



Two new species of *Theلودerma* (Anura: Rhacophoridae) from Vietnam

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Abstract

Two new species of rhacophorid frogs in the genus *Theلودerma* are described from high-elevation montane forest on the Kon Tum and Langbian Plateaus in Vietnam, on the basis of morphological and molecular evidence. Both new species are differentiated morphologically from their congeners by their small body size (<30 mm SVL); absence of vomerine teeth; rugose skin texture with minute, calcified dorsal asperities; no webbing on hands; brownish dorsum; and a bicoloured iris (pale gold in upper third and reddish brown in lower two-thirds). Molecular evidence supports that both new species are members of genus *Theلودerma*, and are distinct from all congeners sampled (uncorrected sequence divergences at the 16S rRNA gene of >8.5% for all *Theلودerma* for which homologous 16S rRNA sequences are available). The new species are differentiated from each other by dorsal pattern, extent of dorsal asperities, and by mitochondrial DNA.

Key words: Anura, Rhacophoridae, Southeast Asia, Vietnam

Introduction

The family Rhacophoridae is a largely arboreal group of frogs containing approximately 320 species and distributed throughout subsaharan Africa, China, Southeast Asia, Japan, Taiwan, the Philippines, and the Greater Sunda Islands (Frost 2011). Due to their high level of diversification, limited number of morphological synapomorphies within groups and unresolved molecular phylogenies, generic allocation within the family is often difficult, and is currently in a state of flux (Li *et al.* 2008, 2009; Yu *et al.* 2009).

Frogs within the rhacophorid genus *Theلودerma* (Tschudi 1838) are small to medium sized and highly arboreal, and grouped mainly on the basis of their tuberculate dorsal skin or presence of dorsal asperities. The genus currently contains 17 species distributed throughout Southeast Asia, southern China and northeastern India, but new species in the genus continue to be discovered, and five have been described in the last decade (Frost 2011).

During recent field surveys in Vietnam, we encountered several small rhacophorid specimens from high elevation forest in both the Kon Tum and Langbian Plateaus (Figure 1). Specimens from both sites were identified morphologically as members of the genus *Theلودerma* on the basis of having tuberculate skin with calcified dorsal asperities on the dorsum, a distinct tympanum, rounded canthus rostralis (versus sharp in *Nyctixalus*), bony ridges from canthus rostralis to occiput absent (versus present in *Nyctixalus*), terminal phalanx with a Y-shaped distal end (versus simple or bifurcate in *Philautus*), and skin of head not co-ossified to the skull (versus skin of head co-ossified to skull in *Nyctixalus*) (Liem 1970; McLeod & Norhayati 2007). However, because no morphological synapomorphy is known for the genus *Theلودerma*, and its monophyly is not certain (Liem 1970; Li *et al.* 2009) we use preliminary molecular evidence to provide independent support of our generic assignment and describe these species as new. Our preliminary molecular phylogeny also provides an opportunity to further examine the genus *Theلودerma*.

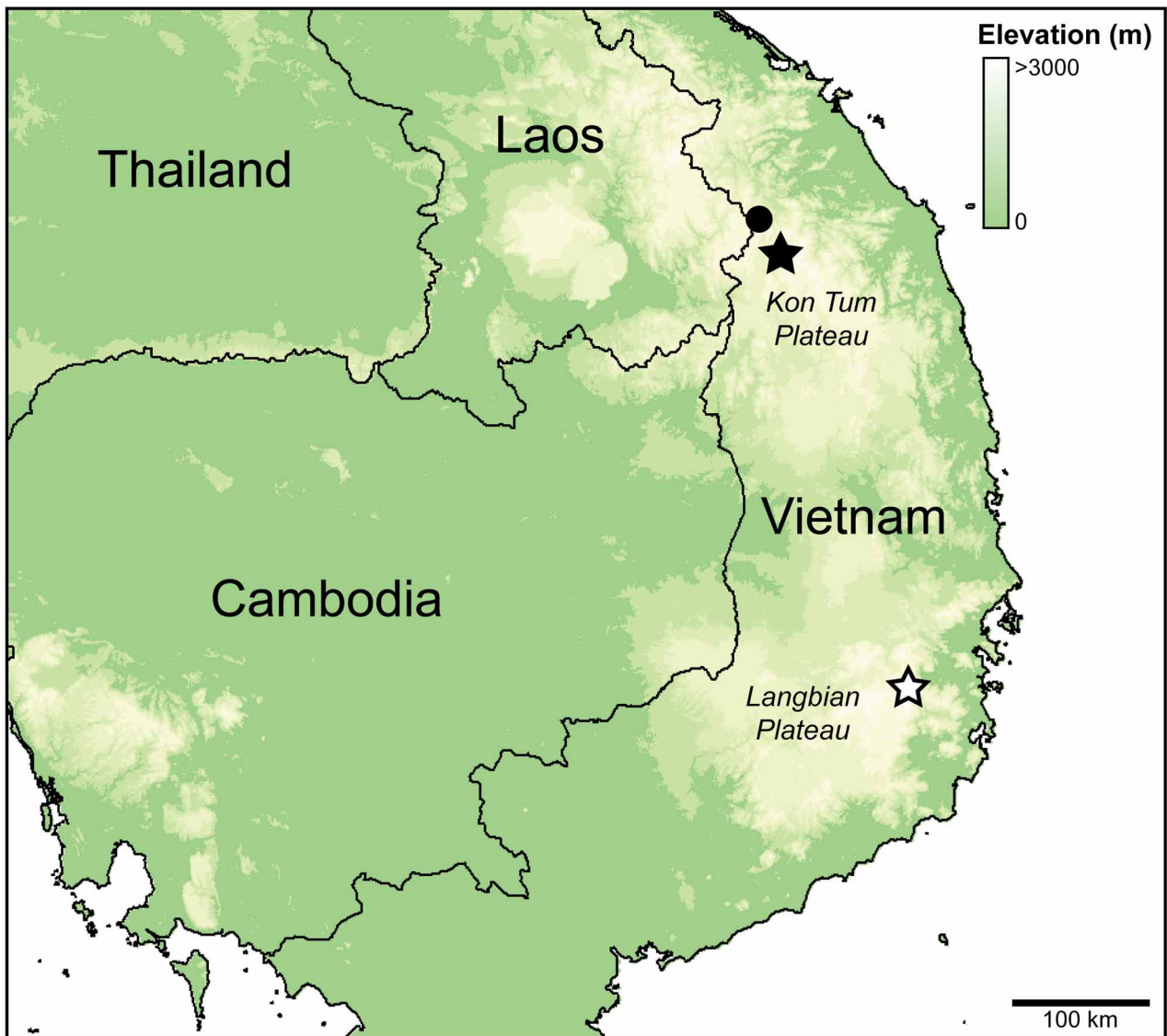


FIGURE 1. Collection locality of *Theلودerma* species from the Kon Tum Plateau (black star), Langbian Plateau (white star), and the *Philautus truongsoneis* (*T. truongsoneis* comb. nov.) specimens examined in this study (black circle).

Material and methods

Morphological data. We recorded morphological data from specimens fixed in 10% formalin and then stored in 70% ethanol. Specimens were deposited at the Australian Museum (AMS). Some specimens currently at the AMS will be deposited at the University of Science, Ho Chi Minh City (UNS) and have been cross-catalogued at both institutions. In these instances, voucher numbers are reported as UNS/AMS. Morphometric data were taken (to the nearest 0.1 mm) with digital calipers. Measurements include snout-vent length (SVL); head length from tip of snout to rear of jaws (HDL); head width at the commissure of the jaws (HDW); snout length from tip of snout to the anterior corner of eye (SNT); diameter of the exposed portion of the eyeball (EYE); interorbital distance (IOD); horizontal diameter of tympanum (TMP); distance from anterior edge of tympanum to posterior corner of the eye (TEY); internarial space (IN); distance from nostril to tip of snout (NS); distance from front of eye to nostril (EN); tibia length with the hindlimb flexed (TIB); manus length from tip of third digit to base of tubercle on prepollex (ML); pes length from tip of fourth toe to base of the inner metatarsal tubercle (PL); and length of inner metatarsal tubercle (IML). All measurements were taken by the first author for consistency. Sex was determined by the presence of nuptial pads, vocal sacs and/or gonadal inspection. Mass was recorded in life (to the nearest 0.1 g), using

TABLE 1. Selected diagnostic characters for species in the genus *Theلودerma*.

Species	Size category ¹	Vomerine teeth	Dorsal asperities	Webbing hands	on	Dorsal colour	Ventral colour	Iris colour	Source
<i>T. andersoni</i>	small	absent	small	absent		uniform dark olive, white tubercles, two yellow spots on middle of flanks, large black spot on groin	yellowish, with fine brown punctulations anteriorly	?	Ahl 1927, 1931
<i>T. asperum</i>	small-medium	absent	small	absent		dark grey brown with large conspicuous white pattern	marbled black and bluish grey/white	reddish brown	Boulenger 1886; Kunz <i>et al.</i> 2010; Rowley <i>pers. obs.</i> ; Taylor 1962.
<i>T. baibengense</i> ²	small	absent	small	absent		black with large conspicuous white patterns	dark with white pattern on belly	reddish brown	Fei <i>et al.</i> 2010; Jiang <i>et al.</i> 2009.
<i>T. bicolor</i>	large	present	large	absent		olive green marbled with black/red-brown	black marbled with white	green with black reticulations	Bourret 1937, 1942; Kunz <i>et al.</i> 2010; Rowley <i>pers. obs.</i>
<i>T. corticale</i>	large	present	large	absent/rudimentary between F3–4		olive green marbled with black	whitish spotted/marbled with black	green with black reticulations	Boulenger 1903; Inger <i>et al.</i> 1999; Kunz <i>et al.</i> 2010.
<i>T. gordoni</i>	large	present	large	absent		dark wood brown with orange patches and darker spots on head	lavender with dark lavender/black flecks and reticulations	silvery with black	Kunz <i>et al.</i> 2010; Rowley <i>pers. obs.</i> ; Taylor 1962
<i>T. horridum</i>	medium	absent	large	present		dark warm brown with black spots	white/blue grey, marbled/spotted with black	pale gold with black reticulations	Boulenger 1903; Chan-ard 2003; Kunz <i>et al.</i> 2010.
<i>T. kwangsiense</i>	large	present	large	absent		green-brown	marbled	greenish	Fei <i>et al.</i> 2010; Liu & Hu, 1962; Kunz <i>et al.</i> 2010; Orlov <i>et al.</i> 2006. Bain <i>et al.</i> 2009.
<i>T. lateriticum</i>	small	absent	small	absent		brick red, with single black mid-dorsal spot	uniform grey-brown with bright white spots	brick-red	Ahl 1931; Bourret 1942; Chan & Norhayati 2009;
<i>T. leporosum</i>	large	present	large	absent		chocolate brown to greyish brown	black mottled with white/bluish grey, underside of toes and fingers bright rose red	pale warm brown, with black reticulations	Günther 1887; Kunz <i>et al.</i> 2010; Tschudi 1838.
<i>T. licin</i>	small	absent	small	present		white to pale brown	white with brown reticulations, throat brown with small white spots	red	Kunz <i>et al.</i> 2010; McLeod & Norhayati 2007.
<i>T. moloch</i>	medium	present	large	absent		grey with black spots	black with faint reticulation	?	Annandale 1912; Bourret 1942; Chanda 1994.

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TABLE 1. (continued)

Species	Size category ¹	Vomerine teeth	Dorsal asperities	Webbing hands	Dorsal colour on	Ventral colour	Iris colour	Source
<i>T. nagalandense</i>	large	present	large	present	large orange-red patches	dark brown to black, no marbling	?	Orlov <i>et al.</i> 2006.
Kon Tum Plateau specimen (<i>T. nebulosum</i> sp. nov.)	small	absent	small, sparse	absent	brown with darker patterning	dark brownish black with pale blue/white marbling on chest and belly	pale gold above, reddish brown below	Present study.
Plateau specimens (<i>T. palliatum</i> sp. nov.)	small	absent	small	absent	pale brown/white with distinct darker brown markings	dark brownish black with pale blue/white marbling on chest and belly	pale gold above, reddish brown below	Present study.
<i>T. phrynoderma</i>	medium	absent	small	present	grey	blackish brown with white spots	?	Ahl 1927, 1931; Bourret 1942.
<i>T. rhododiscus</i>	small	absent	small	absent	tea brown	chest mottled brown, belly brownish-black scattered with gray-white network, disks orange-red ventrally	red brown	Bain & Nguyen 2004; Fei <i>et al.</i> 2009, 2010; Liu & Hu 1962.
<i>T. ryabovi</i>	medium	absent	small	present	light beige with lilac patterns and black spots to almost uniformly black.	dark grey without pattern	dark brown	Kunz <i>et al.</i> 2010; Orlov <i>et al.</i> 2006.
<i>T. stellatum</i>	small-medium	absent	small	present	brown with white/lavender grey markings	brown/black, reticulated with cream	brown/gold with black reticulations	Rowley <i>pers. obs.</i> ; Taylor 1962.
<i>P. truongsoneensis</i> (<i>T. truongsoneense</i> comb. nov.)	small	absent	absent	absent	pale brown with darker brown markings	dark grey with round speckles	pale gold above, reddish brown below	Orlov & Ho 2005.

¹ adult size categories: small (<35 mm), medium (35–45 mm), large (>45 mm).

² *Theلودerma baibengensis* (Jiang, Fei & Huang 2009) is corrected to *T. baibengense* to reflect the neuter gender of the genus *Theلودerma*.

Pesola scales. Radiographs of the holotypes were also prepared to examine gross osteological features. Terminology for describing eye colouration in life follows Glaw and Vences (1997). Webbing formula follows that proposed by Savage and Heyer (1967), and modified by Myers and Duellman (1982) and Savage and Heyer (1997). Tadpole labial tooth row formulae (LTRF) follows Altig and McDiarmid (1999). We obtained comparative morphological data from museum specimens of *Theلودerma* from the AMS and the Vietnam National Museum of Nature (VNMN), photographs of these specimens in life (Appendix), and from the literature (Table 1). Based on the similarity of the newly collected specimens to *Philautus truongsoneis* (small body size, iris pale gold in upper third and reddish below, pale brown dorsum with distinct dark brown markings, dark brown lateral surfaces of head and body, and no webbing on hands), we have included this species in morphological comparisons and molecular analysis.

Molecular data. In addition to the Kon Tum and Langbian specimens, seven of the 17 species putatively belonging to the genus *Theلودerma* were included in the molecular analysis, the most extensive sampling of the genus to date. The type specimen for the genus, *T. leporosum*, is missing from our analysis, however this species is known only from Malaysia and Indonesia, and is morphologically very similar to *T. gordonii*, which is included. Also missing is *Theلودerma andersonii* with the type locality of northern Myanmar; *T. baibengensis*, recently described from Medog County, Xizang, China, and most morphologically similar to *T. asperum*; *T. horridum* with the type locality of Pattani, Thailand, but known from the extreme southern peninsula of Thailand and Malaysia; *T. kwangsiense*, known only from the type locality in Guangxi, China; the recently described *T. lateriticum* from Lao Cai Province in northern Vietnam; the recently described *T. licin*, from peninsular Malaysia, and most genetically similar to *T. asperum* according to the original description; *T. nagalandense* known only from the type locality in Nagaland, India; *T. phrynoderma* from northern Myanmar; and *T. ryabovi* known only from the type locality of Kon Tum Province, Vietnam. We included *Philautus truongsoneis* (Orlov & Ho 2005) in the molecular analysis due to its morphological similarity with the new Kon Tum and Langbian specimens, along with members of possible sister groups to the genus as outgroups: *Nyctixalus pictus*, *Kurixalus eiffingeri* (type species for the genus *Kurixalus*) and *Philautus aurifasciatus* (type species for the genus *Philautus*). Locality information and accession numbers for all sequences included in the analysis can be found in Table 2.

TABLE 2. Samples and sequences used in our preliminary phylogenetic study of the genus *Theلودerma*.

Species assigned	Locality	Voucher no.	GenBank no.
<i>Theلودerma asperum</i>	China, Guangxi Province	-	EF646375
	China, Yunnan Province	060821203Rao	GQ285677
	China, Hainan Island	HN0806100	GQ285678
	Vietnam, Tuyen Quang Province	ROM 30246	AF458148
<i>Theلودerma bicolor</i>	Vietnam, Lao Cai Province	MNHN 199.5986	AY880529
<i>Theلودerma corticale</i>	Vietnam, Vinh Phu Province	AMNH A161499	DQ283050
<i>Theلودerma gordonii</i>	Vietnam, Nghe An Province	VNMN 03013	JN688167
<i>Theلودerma moloch</i>	China, Xizang/Tibet	6255Rao	GQ285679
<i>Theلودerma</i> “Kon Tum” (<i>T. nebulosum</i> sp. nov.)	Vietnam, Kon Tum Province	AMS R 173409, UNS00141/ AMS R 173877 (2)	JN688168–9
<i>Theلودerma</i> “Langbian” (<i>T. palliatum</i> sp. nov.)	Vietnam, Lam Dong Province	AMS R 173130–1 (2)	JN688172–3
<i>Theلودerma rhododiscus</i>	Vietnam, Ha Giang Province	AMNH A163893	DQ283393
<i>Theلودerma stellatum</i>	Vietnam, Binh Thuan Province	AMS R 173283	JN688170
	Cambodia, Mondulhiri Province	AMS R 174047	JN688171
<i>Philautus truongsoneis</i> (<i>T. truongsoneis</i> comb. nov.)	Vietnam, Quang Nam Province	AMS R 171510	JN688174
<i>Nyctixalus pictus</i>	Thailand, Phang Nga Province	MNHN1999.7718	AY880502
<i>Kurixalus eiffingeri</i>	Japan, Okinawa Islands	A120	DQ468673
<i>Philautus aurifasciatus</i>	Indonesia, Java	ZRC.1.5266	AY141850

Total genomic DNA was extracted from tissues using DNeasy tissue extraction kits (Qiagen). We used the primers 16SAR and 16SBR of Palumbi *et al.* (1991) to amplify a ~550 base pair fragment of the 16S rRNA gene. Standard PCR protocols were used and PCR products were purified using ExoSap-IT (USB Corporation, OH, USA). Purified templates were sequenced directly by Macrogen (Seoul, Korea). Sequences were validated using Sequencher 4.10 (Gene Codes, Ann Arbor, MI). Homologous fragments of 16S obtained from GenBank included in the analysis and all sequences were aligned using the Clustal option in MEGA 5 and refined by eye. Uncorrected pairwise sequence divergence was calculated using MEGA 5. We used Akaike Information Criterion as implemented in jModelTest 0.1.1 to select the best-fit model of nucleotide substitution (Posada & Buckley 2004; Posada & Crandall 1998), which was then used in all model-based phylogenetic inference.

Bayesian phylogenetic analyses were performed in MrBayes 3.1.2 (Huesenbeck and Ronquist 2001; Ronquist & Huelsenbeck 2003) under a GTR+ Γ model of sequence evolution (general time reversible model with Gamma distributed substitution rates). Four independent Markov Chain Monte Carlo searches were run for 10 million generations, sampled every 1000 generations, each with four chains, and default priors. Output files were examined visually in Tracer v1.5 (Rambaut & Drummond 2007), to assess stationarity and determine the number of generations to remove as burn-in. To be conservative we considered 1 million generations from each run as burn-in, and removed 1000 trees (=1 million generations) before summarizing topology and posterior probabilities. Trees were visualized using the FigTree v1.1.2 program, available at <http://tree.bio.ed.ac.uk/software/figtree/>. We consider branches receiving $\geq 95\%$ posterior probabilities to be well-supported (Wilcox *et al.* 2002).

Maximum-likelihood phylogenetic analyses were performed in GARLI 1.0 (Zwickl 2006) under the same GTR+ Γ model with model parameters estimated during the search. 100 independent searches were performed, each starting with a random tree. Each search was terminated after 200000 generations with no significant topological improvement. The best likelihood from each of these runs was selected as our maximum-likelihood estimate, and statistical support for this topology was obtained by running 1000 bootstrap replicates in GARLI with the same settings, except that the termination criterion was reduced to 10000 generations with no significant topological improvement. Split support was calculated using SumTrees 3.1.0 (Sukamaran & Holder 2010). We consider branches receiving $\geq 70\%$ bootstrap support to be well-supported (Hillis & Bull 1993).

We created our preliminary molecular phylogenies primarily to support the placement of our newly collected specimens within the genus *Theلودerma*, rather than to resolve phylogenetic relationships within the group.

Results

Morphological data. Our specimens from the Kon Tum Plateau and the Langbian Plateau differed from each other and from all other named species in the genus *Theلودerma* (Table 1). Although specimens from both sites differed from all species by a combination of body size, presence of vomerine teeth, size of dorsal asperities, the extent of hand webbing, and dorsal and ventral colouration, eye colour was the most obvious character distinguishing the two new species from other members of the genus *Theلودerma*. Eye colour is considered a reliable taxonomic character (Glaw & Vences 1997), and to our knowledge, the bicoloured iris (pale gold in upper third and dark red in lower two-thirds) present in specimens from both sites is unique among all rhacophorid species from Southeast Asia with for which iris colour has been documented, with the exception of *Nyctixalus pictus*, *N. margaritifera*, and *Philautus truongsoneusis* (Figure 2) (Alcala & Brown 1998; Chan-ard 2003; Fei *et al.* 2010; Inger & Stuebing 2005; Iskandar 1998; Kunz *et al.* 2010; Malkmus *et al.* 2002; Manthey & Grossmann 1997; Neang & Holden 2008; Nguyen *et al.* 2009; Rowley pers. obs.).

Molecular data. The newly collected specimens from the Kon Tum and Langbian Plateaus are embedded within a clade containing all sampled *Theلودerma* species (with the exception of *T. moloch*; Clade I, Figure 3). This clade receives high support (1.00 Bayesian posterior probability/80% Maximum Likelihood bootstrap support). *Philautus truongsoneusis* and *Nyctixalus pictus* were also embedded within this clade, although the placement of the latter is poorly resolved.

Our preliminary molecular phylogenies suggest that the Kon Tum Plateau specimens are most closely related to *Philautus truongsoneusis*, differing by 8.5% from the single *P. truongsoneusis* analysed and $>8.5\%$ at the 16S rRNA gene from all *Theلودerma* in the analysis. The Langbian specimens appear most closely related to *T. rhododiscus*, but differed by 8.5–8.8% from this species and $>8.5\%$ at the 16S rRNA gene from all *Theلودerma* specimens in the analysis.

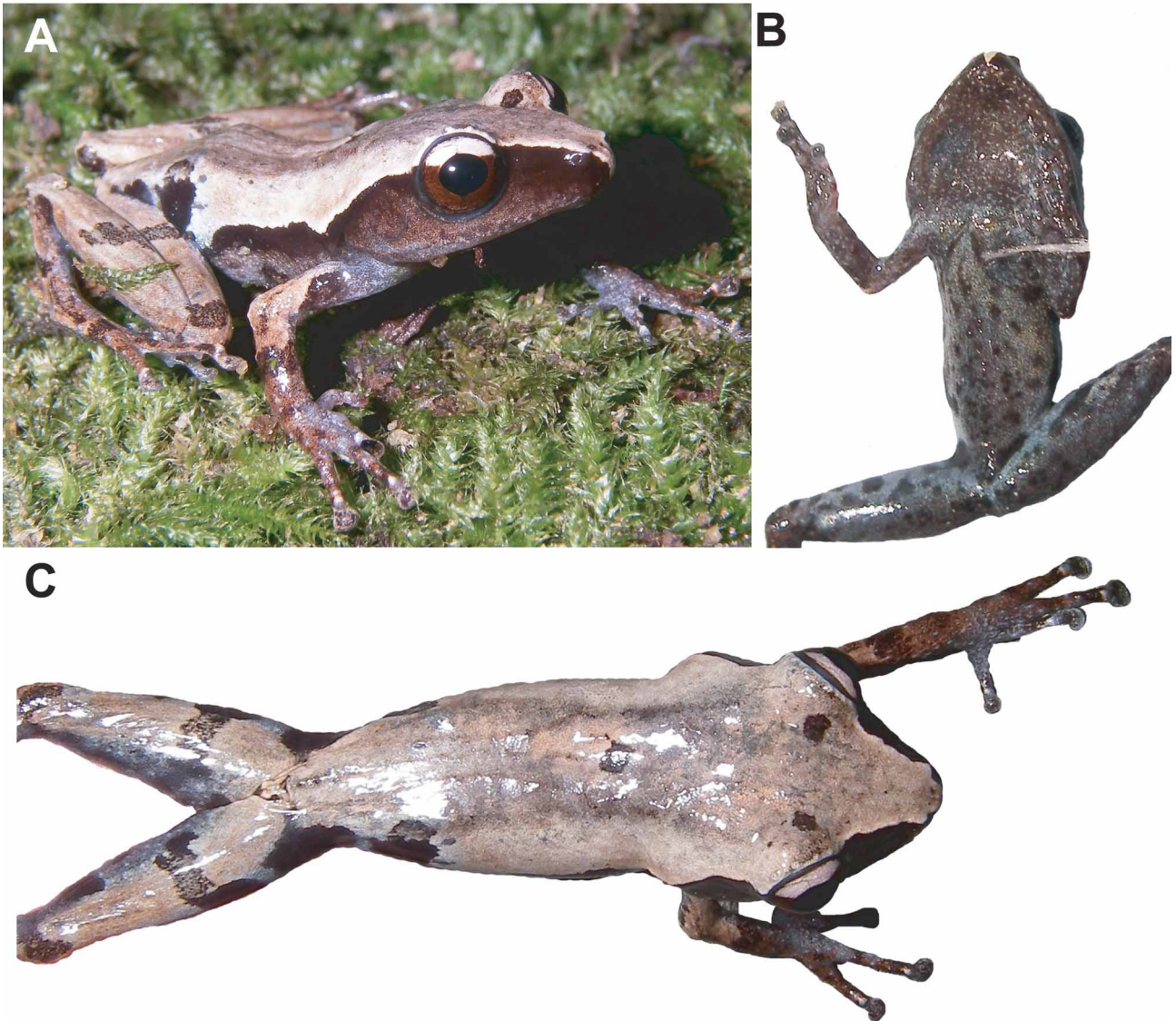


FIGURE 2. *Philautus truongsoneensis* (*Theloderma truongsoneense* comb. nov.) (AMS R 171510) in life. (A) dorsolateral view, diurnal colouration, (B) ventral view, diurnal colouration, and (C) dorsal view, diurnal colouration.

Taxonomic conclusions. Based upon our preliminary molecular results, *Theloderma* as currently understood is not a monophyletic genus. If the *T. moloch* sequence on GenBank has been correctly identified, the species is unlikely to be a true member of the genus. However, further research is required in order to verify the specific identity of the sequence on GenBank, particularly given the striking morphological similarity of adults and tadpoles of this species to members of the genus *Theloderma* (Annandale 1912). Both morphological and molecular data suggest that *Philautus truongsoneensis* belongs to the genus *Theloderma*, and we suggest that the generic placement of this species be transferred. On the basis of our preliminary data, the position of *N. pictus* is unresolved, but the species may fall within the genus *Theloderma*. The morphological similarity between *Nyctixalus* and members of *Theloderma*, especially with respect to iris colouration, support this possibility, and the validity and phylogenetic placement of the genus *Nyctixalus* certainly warrants further investigation. Our preliminary molecular phylogeny also provides evidence of multiple lineages within individuals currently assigned to *T. asperum*.

Both morphological and molecular data sets provide evidence that newly collected specimens from both the Kon Tum and Langbian Plateaus represent new species within the genus *Theloderma*, and these species are described here as new.

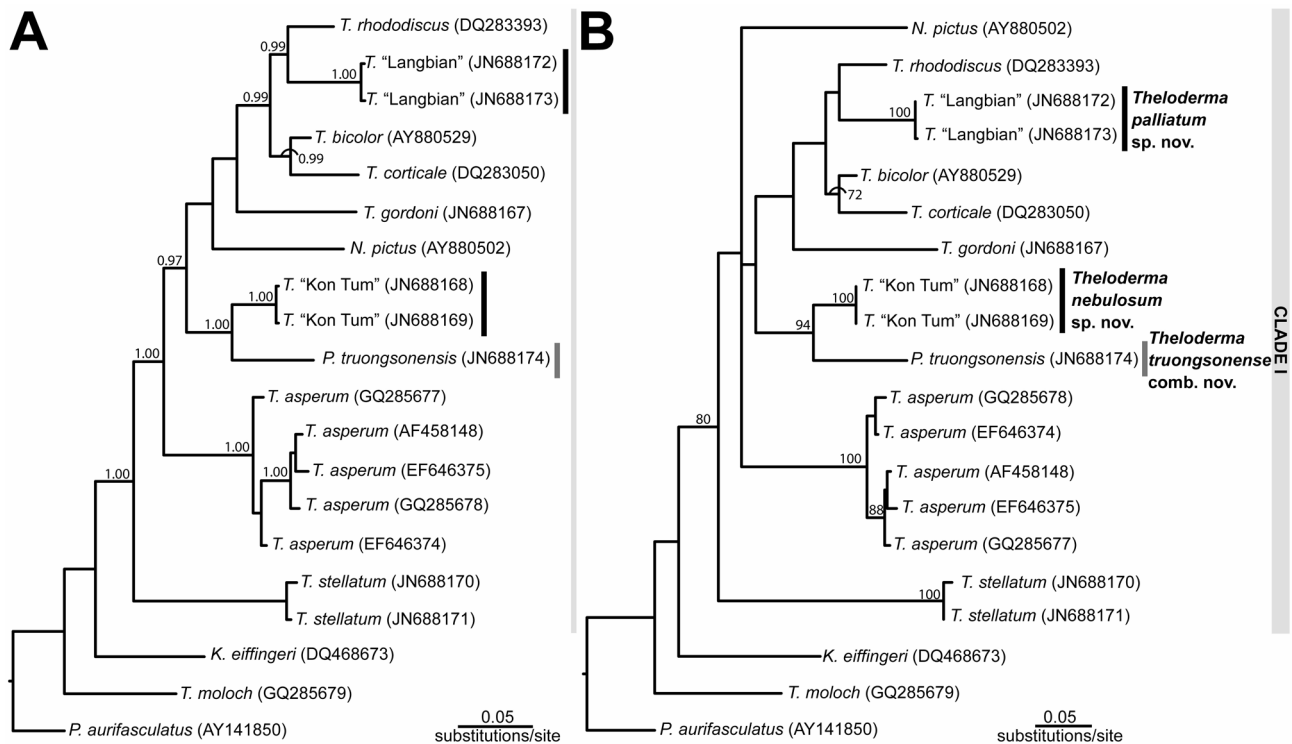


FIGURE 3. (A) Bayesian inference and (B) Maximum-likelihood tree based on 16S ribosomal RNA mitochondrial gene sequences for species putatively assigned to *Theلودerma* and for possible outgroups (*Nyctalix pictus*, *Kurixalus eiffingeri* and *Philautus aurifasciatus*). Numbers on branches are Bayesian posterior probabilities (values ≥ 0.95 shown) and ML bootstrap values (values ≥ 70 shown).

Theلودerma nebulosum sp. nov.

Holotype: AMS R 173409, adult female, on a leaf of tree, >10 m from stream, in bamboo/montane evergreen forest in Ngoc Linh Nature Reserve, Dak Glei District, Kon Tum Province, Vietnam (15.06° N, 108. 107.86° E, ~2000 m). Collected at ~ 20:00 h on 3 April 2010 by J. J. L. Rowley, Le T. T. D., Dau Q. V. and Hoang D. H.

Other material. UNS 00141/AMS R 173877, eight tadpoles collected inside a water-filled hole (30 cm diameter, 20 cm deep) in a dead tree, approximately 1 m from the ground, on 17 July 2009 in Ngoc Linh Nature Reserve, Dak Glei District, Kon Tum Province, Vietnam (15.08° N, 108. 107.96° E, ~1950 m). Collected by Le T. T. D., Dau Q. V., Le V. K. and Nguyen Q. H.

Etymology. specific epithet *nebulosus* L., meaning misty or cloudy, in reference to the type locality the species, high-elevation forest often shrouded in cloud.

Suggested common name. Misty moss frog (English), Éch cây sần sương mù (Vietnamese).

Diagnosis. The new species is assigned to the genus *Theلودerma* by the presence of tuberculate skin on the dorsum, a distinct tympanum, terminal phalanx with a Y-shaped distal end, intercalary cartilage between the terminal and penultimate phalanges of digits, tips of digits expanded into large disks bearing circummarginal grooves, absence of co-ossification of the head skin to the skull (Liem 1970), and molecular data. *Theلودerma nebulosum* sp. nov. is distinguished from all other *Theلودerma* by a combination of (1) small body size (29.2 in a single adult female), (2) absence of vomerine teeth, (3) only scattered, minute dorsal asperities, (4) no webbing on hands, (5) brown dorsum with indistinct darker brown longitudinal markings and brownish black lateral surfaces extending from snout to groin, and (6) a bicoloured iris, being pale gold in upper third and dark red in lower two-thirds.

Description of holotype. Body relatively robust; head length equals head width; snout bluntly truncate in dorsal view, rounded in profile; canthus rostralis relatively indistinct, rounded; loreal region slightly concave; interorbital region slightly convex; nostrils oval, only slightly protuberant, without flap of skin laterally, much closer to tip of snout than eye; pupil diamond-shaped, horizontal; tympanum distinct, tympanic rim elevated relative to skin of

temporal region, 67% of eye diameter; pineal ocellus absent; skin not co-ossified to forehead; vomerine teeth absent; choanae oval, at margins of roof of mouth; tongue attached anteriorly, wide, notched posteriorly; supratympanic fold present, extending to just beyond level of axilla. Forelimbs slender, relative length of fingers I < II < IV < III; tips of all fingers with well-developed disks with distinct circummarginal grooves, disks relatively wide compared to finger width (third finger disk width 209% third finger width), disks slightly wider than long (third finger disk width 135% of length), third finger disk width 77% of tympanum diameter; webbing on fingers absent; dermal fringing absent; subarticular tubercles prominent, rounded, formula 1, 1, 2, 2; supernumerary tubercles present; two palmar tubercles; accessory palmar tubercles present, small; prepollex with low tubercle. Relative length of toes I < II < III < V < IV; tips of toes with well-developed disks with distinct circummarginal grooves; disks smaller than those of fingers; webbing formula I2⁺-3II2⁺-3⁺III2⁺-3½IV3⁺-2⁺V; subarticular tubercles rounded, distinct, formula 1, 1, 2, 3, 2; inner metatarsal tubercle distinct, oval; outer metatarsal tubercle indistinct. Dorsal skin very weakly rugose with very sparsely distributed minute, pearly asperities; ventral surface of thighs and posterior surface of belly coarsely granular, chest and throat smooth. Dermal fringes and pointed projection at tibiotarsal articulation absent.

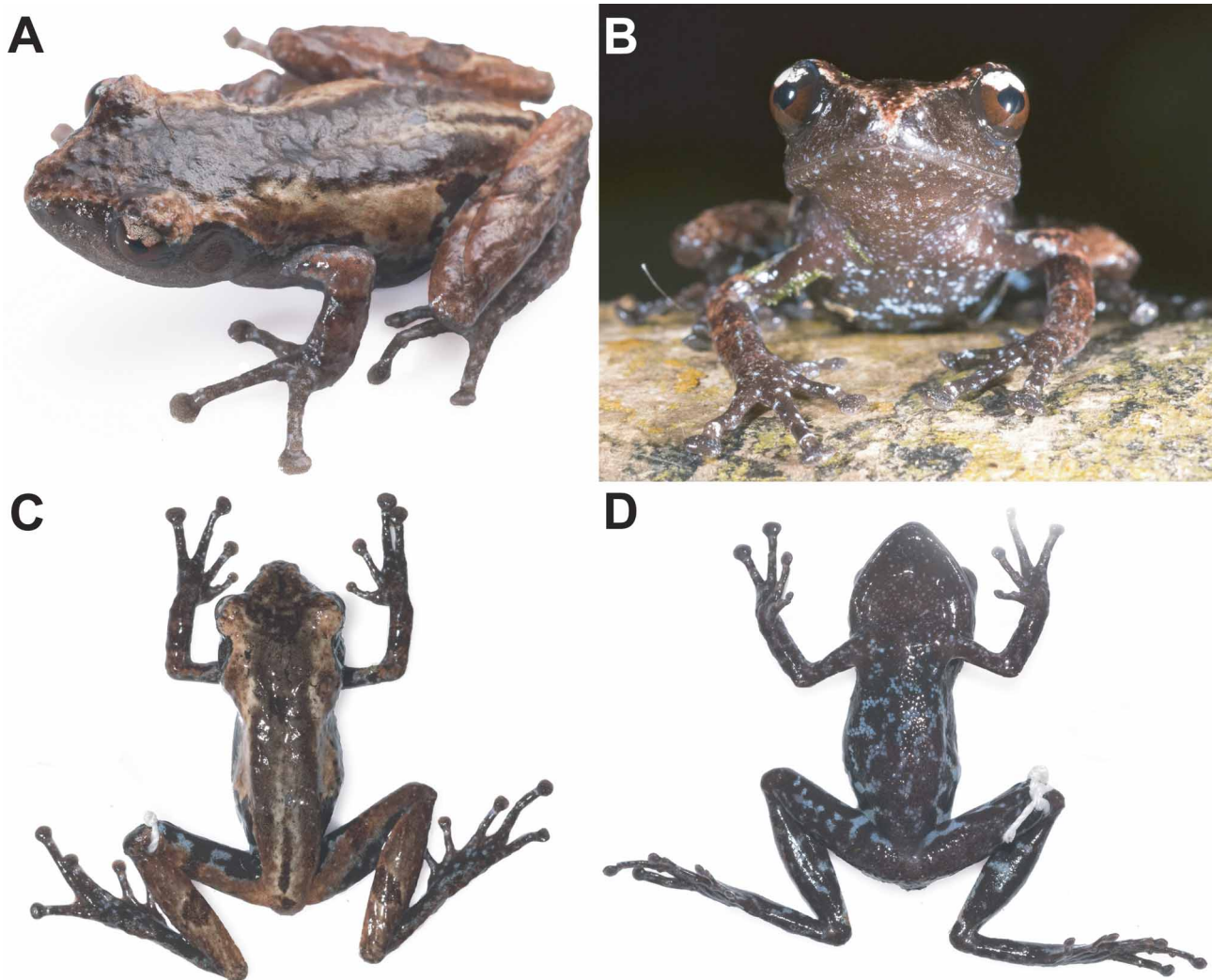


FIGURE 4. Adult female holotype of *Theلودerma nebulosum* sp. nov. (AMS R 173409) in life. (A) dorsolateral view, nocturnal colouration, (B) anterior view, diurnal colouration (C) dorsal view, diurnal colouration, and (D) ventral view, diurnal colouration.

Colour of holotype in life. Dorsum brown with indistinct darker brown longitudinal markings running along midline from snout, including anterior portions of eyelid, to vent; dorsolateral surfaces of body paler brown,

slightly mottled; darker spot above cloaca and a darker line slightly anterior to cloaca, running along dorsal midline. Ventral surface of tibiotarsus and arms brown with single, indistinct, dark brown band running across ventral surface of tibiotarsus and thigh, and on to body; when leg is adpressed, forms a continuous line. Dark brown inguinal blotches. Ventral surface of hands and feet mostly greyish black with pale bluish grey spots, brown along outside margins; ventral surface of toe-pads brown. Dark brownish black lateral surfaces, extending from snout, through eye and over tympanum to groin; pale bluish white speckling on side of head and on anterior flanks; pale bluish white marbling on posterior surfaces of flanks. Ventral surface of body brownish black with pale bluish white marbling on chest, inguinal region, anterior and posterior surface of thighs; faint white speckling on throat and ventral surfaces of arms. Iris pale gold in upper third, and dark reddish brown in lower two-thirds; division of eye colour matches skin coloration adjacent to eye (Figure 4).

Colour of holotype in preservative. As in life, but paler brown colours on dorsum fade to creamy grey (Figure 5).

Variation. Measurements of the holotype are in Table 3. As was noted for *T. licin* (McLeod & Norhayati 2007), the new species has the ability to change colour over time, albeit to a lesser degree than was observed in the Langbian Plateau *Theloderma* specimens (described below). Upon capture (at night), the dorsal pattern was more distinct.

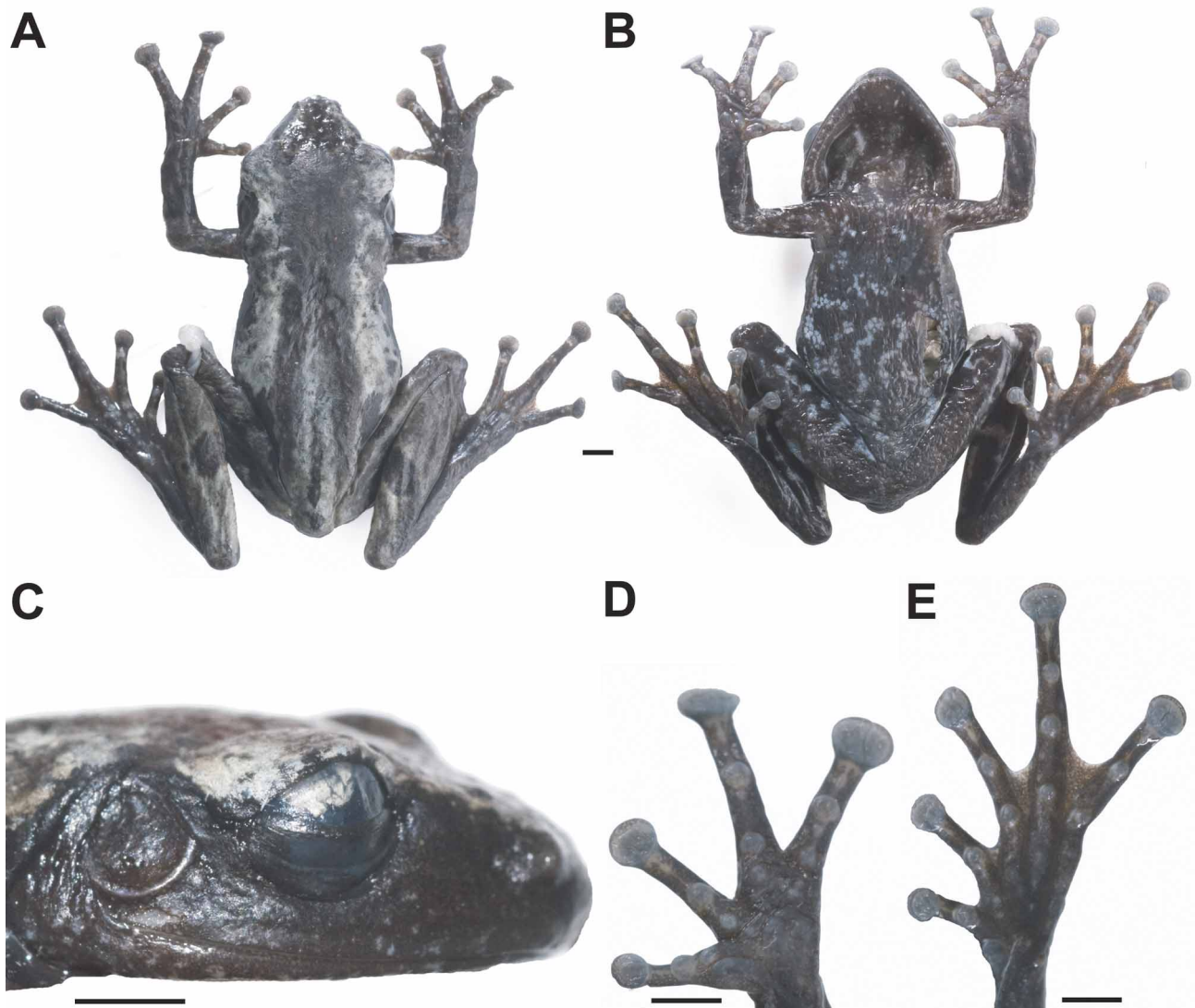


FIGURE 5. Adult female holotype of *Theloderma nebulosum* sp. nov. (AMS R 173409) in preservative (A) Dorsal view, (B) ventral view, (C) lateral view of head, (D) ventral surface of left hand, and (E) ventral surface of left foot. Scale bars = 2 mm.

Tadpole. Tadpoles were assigned to the new species based upon the lack of sequence divergence between the tadpole and adults frog at the 16S rRNA gene. Body shape rounded and depressed, eyes dorsal; nares small and nearer to snout than eye; vent tube medial; spiracle sinistral; tail tip broadly rounded. The oral apparatus is anteroventral, almost terminal. The spiracle is ventrolateral and lacks a free tube. The labial tooth row formula (LTRF) is 4(2–4)/3, the marginal papillae have a large dorsal gap. Tadpoles have a uniform dark brown body in preserve, with paler brown tail muscle and transparent tail fin with fine brown speckling (Figure 6). Measurements (in mm) of one tadpole at developmental stage 28 (Gosner 1960): total length 24.6 mm, body length 10.3 mm, tail length 14.3 mm, maximum tail height 4.6 mm, tail muscle height 2.8 mm, interorbital distance 2.1 mm, oral disk width 2.5 mm, oral disk height 0.9 mm. Seven other tadpoles were collected in the same water body, ranging from developmental stage 26–30 and body length 6.0–13.3 mm.

TABLE 3. Measurements (mm) of *Theلودerma nebulosum* **sp. nov.** and *Theلودerma palliatum* **sp. nov.** Abbreviations defined in text.

	<i>Theلودerma nebulosum</i> sp. nov.	<i>Theلودerma palliatum</i> sp. nov.		
	AMS R 173409*	AMS R 173130	AMS R 173131*	UNS 00140/ AMS R 173508
Sex	Female	Male	Male	Juvenile
SVL	29.2	26.1	26.4	17.1
HDL	10.0	9.8	9.6	7.1
HDW	10.0	9.5	8.9	6.3
SNT	5.0	4.4	4.3	2.8
EYE	3.3	3.1	3.2	2.5
IOD	3.6	3.4	3.5	2.5
TMP	2.2	2.0	2.0	1.3
TEY	0.7	0.5	0.7	0.7
IN	3.1	2.6	2.7	2.1
NS	2.1	1.6	1.6	1.1
EN	3.0	2.8	2.8	1.8
TIB	15.3	14.4	14.3	8.4
ML	9.2	7.7	7.9	4.6
PL	14.3	11.6	12.2	6.6
IMT	1.3	1.2	1.4	0.7
HDW:HDL	1.00	0.97	0.93	0.89
HDL:HDW	1.00	1.03	1.08	1.13
TIB:SVL	0.52	0.55	0.54	0.49
HDL:SVL	0.34	0.38	0.36	0.42
TMP:EYE	0.67	0.65	0.63	0.52
Weight (g)	1.7	1.3	1.3	–

*holotype

Distribution and ecology. The new species is known only from montane evergreen forest at ~2000 m elevation in Ngoc Linh Nature Reserve (Figure 7). At this elevation, temperatures during the coldest months are 5–6°C and temperatures during the hottest months are < 20°C (Le *et al.* 1999). Conditions are also extremely wet, with almost constant mist and approximately 250 rain days per year (Le *et al.* 1999). Specimens of the new species were collected at 15.8°C and 90% relative humidity (July 2009) and ~17°C and 95% relative humidity (March–April 2010).

Comparisons. The small body size; absence of vomerine teeth; minute, very sparsely scattered dorsal asperities; no webbing on hands; brown dorsum with indistinct darker brown longitudinal markings and dark brown lat-

eral surfaces extending from snout to groin; and a distinctly bicoloured iris distinguishes *T. nebulosum* **sp. nov.** from all species of *Theلودerma* (Table 1). *Theلودerma nebulosum* **sp. nov.** appears most morphologically similar to the small *T. lateriticum*, *T. licin*, *T. rhododiscus*, *T. truongsongense* comb. nov. and the newly collected Langbian Plateau specimens (described below). *Theلودerma nebulosum* **sp. nov.** differs morphologically from *T. lateriticum* by having a brown dorsum with indistinct darker brown longitudinal markings (versus a dorsum with a deep brick-red wash overtop dark black-green), minute, sparsely scattered dorsal asperities not visible with the naked eye (versus distinctly white dorsal asperities) and a distinctly bicoloured iris (versus uniformly deep brick red iris). From *T. licin*, *T. nebulosum* **sp. nov.** differs by lacking webbing or fringing on the hands (versus lateral dermal fringes and basal webbing on the hands), having a brown dorsum with darker brown longitudinal markings (versus a uniformly coloured dorsal surface), and a distinctly bicoloured iris (versus uniformly red iris). From *T. rhododiscus*, *T. nebulosum* **sp. nov.** differs by having the ventral surfaces of the disks being brown to greyish brown (versus orange-red), and a distinctly bicoloured iris (versus uniformly reddish brown). From *T. truongsongense* comb. nov. (Figure 2), *T. nebulosum* **sp. nov.** differs by having a brown dorsum with indistinct darker brown longitudinal markings (versus a pale brown dorsum with small, distinctly darker brown blotches and no longitudinal lines), minute, sparsely scattered dorsal asperities (versus no dorsal asperities), and a black/dark brown belly and ventral surface of thighs, with white/pale brown marbling (versus a grey belly and thighs with white spots). From the Langbian Plateau specimens (described below), *T. nebulosum* **sp. nov.** differs by having a brown dorsum with darker brown longitudinal markings (versus a pale to medium brown dorsum with characteristic dark brown blotches), more sparsely scattered dorsal asperities and slightly less webbing on the feet. In addition, *Theلودerma nebulosum* **sp. nov.** has uncorrected sequence divergences at the 16S rRNA gene of >8.5% for all *Theلودerma* for which homologous 16S rRNA sequences are available.

The tadpole of *T. nebulosum* is very similar in body shape and proportions to other *Theلودerma* species for which tadpoles have been described: *T. asperum* (Leong & Lim 2003), *T. corticale* (Kunz *et al.* 2010), *T. horridum* (Boulenger 1903), *T. moloch* (Annandale 1912), and *T. stellatum* (Inger *et al.* 1999; Wassersug *et al.* 1981). The LTRF of the new species, 4(2–4)/3, is the same as reported in *T. stellatum* (Inger *et al.* 1999; Wassersug *et al.* 1981) and *T. moloch* (Annandale 1912), but differs from that reported for *T. asperum* 3(2–3)/3(1) (Leong & Lim 2003).

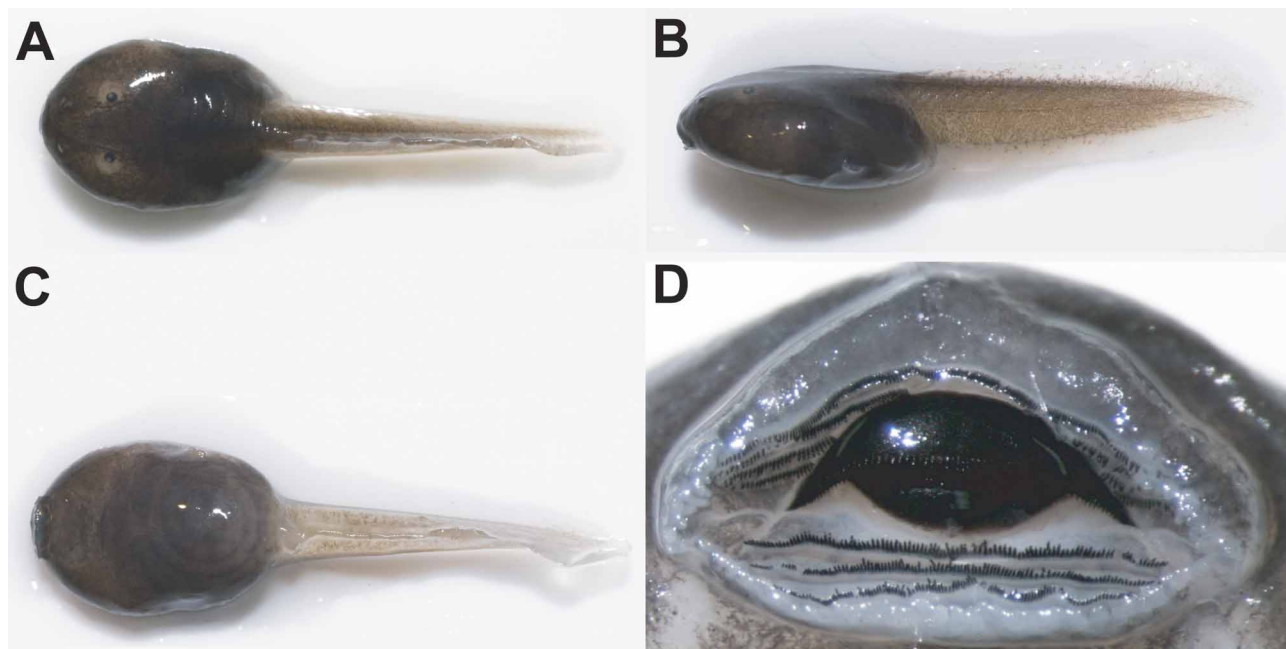


FIGURE 6. Tadpole of *Theلودerma nebulosum* **sp. nov.** (UNS 00141/AMS R 173877) in preservative. (A) dorsal view, (B) lateral view (C) ventral view, and (D) oral disk.



FIGURE 7. Habitat at type locality of *Theloderma nebulosum* sp. nov. in Ngoc Linh Nature Reserve, Kon Tum Province, Vietnam.

***Theloderma palliatum* sp. nov.**

Holotype: AMS R 173131, adult male, on tree leaf approximately 1 m above the ground, >10 m from stream, in montane evergreen forest in Bidoup-Nui Ba National Park, Lac Duong District, Lam Dong Province, Vietnam (12.1865° N, 108.7151° E, 1625 m). Collected at 22:30 h on 26 July 2010 by Le T. T. D.

Paratypes: AMS R 173130, adult male, on a leaf of tree approximately 1 m above the ground, >10 m from stream, in montane evergreen forest in Bidoup-Nui Ba National Park, Lac Duong District, Lam Dong Province, Vietnam (12.1865° N, 108.7151° E, 1625 m). Collected at 22:35 h on 26 July 2010 by Le T. T. D. UNS 00140/AMS R 173508, juvenile, on the ground, approximately 2 m from a small, rocky stream, in montane evergreen forest in Bidoup-Nui Ba National Park, Lac Duong District, Lam Dong Province, Vietnam (12.1735° N, 108.6991° E, ~1500 m). Collected at night on 18 August 2009 by Le T. T. D.

Etymology. specific epithet from *palliatum* L., meaning cloaked or disguised, in reference to the ability of the new species to change dorsal colouration and patterning from relatively dull to highly contrasting.

Suggested common name. Cloaked moss frog (English),Ếch cây sần trá hình (Vietnamese).

Diagnosis. The new species is assigned to the genus *Theلودerma* by the presence of tuberculate skin on the dorsum, a distinct tympanum, terminal phalanx with a Y-shaped distal end, intercalary cartilage between the terminal and penultimate phalanges of digits, tips of digits expanded into large disks bearing circummarginal grooves, and the absence of co-ossification of the head skin to the skull (Liem 1970). *Theلودerma palliatum* **sp. nov.** is distinguished from all other *Theلودerma* by a combination of (1) small body size (26.1–26.4 in two adult males), (2) absence of vomerine teeth, (3) presence of minute dorsal asperities, (4) no webbing on the hands, (5) pale to medium brown dorsum with characteristic dark brown blotches and dark brown lateral surfaces extending from snout to groin, and (6) a bicoloured iris, being pale gold in upper third and dark red in lower two-thirds.

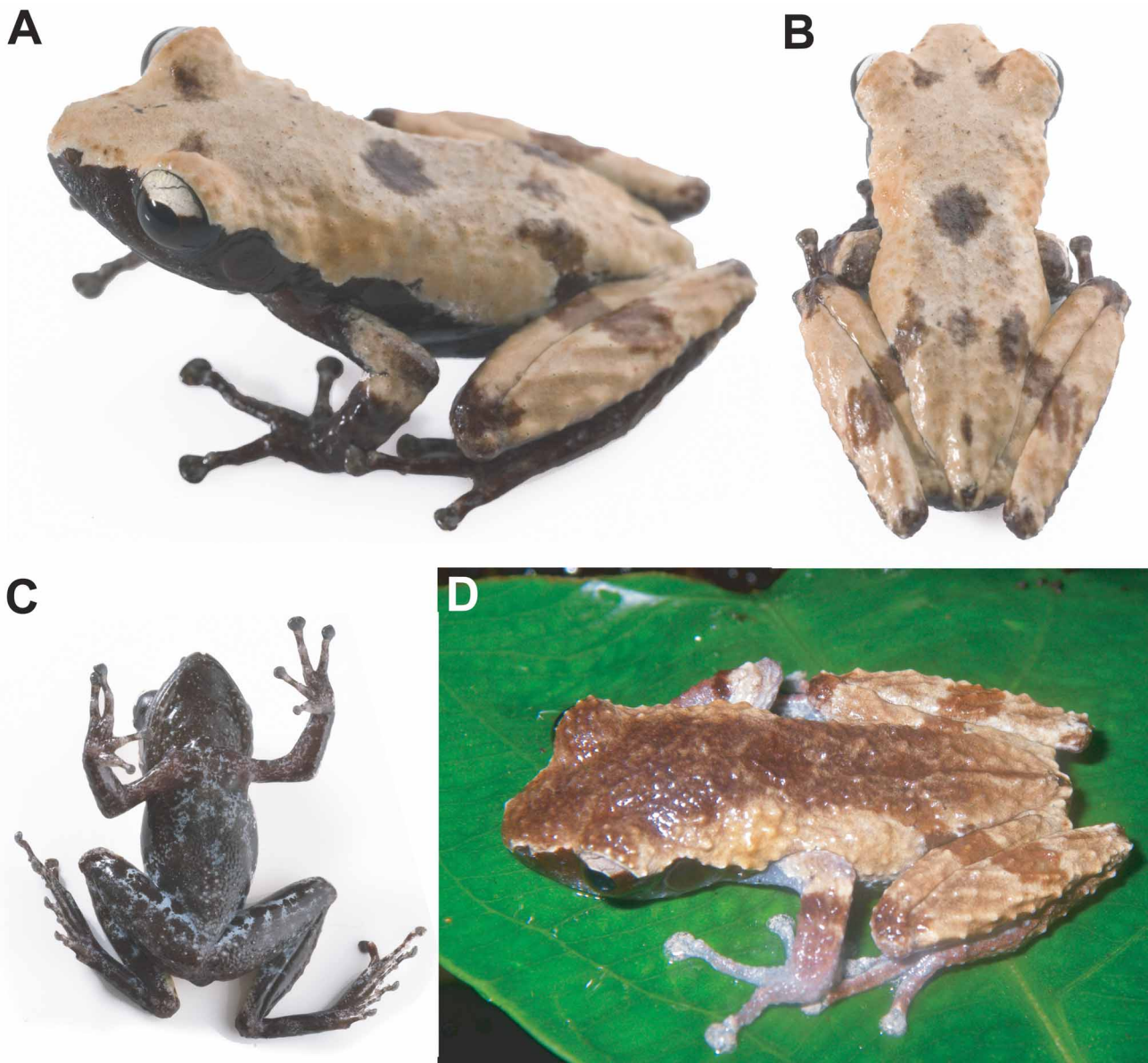


FIGURE 8. Adult male holotype of *Theلودerma palliatum* **sp. nov.** (AMS R 173131) in life (A) dorsolateral view, diurnal colouration, (B) dorsal view, diurnal colouration (C) ventral view, and (D) *in situ* with nocturnal colouration.

Description of holotype. Body relatively slender; head length 90% of head width; snout bluntly truncate in dorsal view, truncate in profile; canthus rostralis relatively indistinct, rounded; loreal region sloping, slightly concave; interorbital region slightly convex; nostrils oval, not protuberant, without flap of skin laterally, much closer to tip of snout than eye; pupil diamond-shaped, horizontal; tympanum distinct, tympanic rim elevated relative to skin of temporal region, 63% of eye diameter; pineal ocellus absent; skin not co-ossified to forehead; vomerine teeth absent; choanae oval, at margins of roof of mouth; tongue attached anteriorly, wide, deeply notched posteriorly;

vocal sac and vocal sac openings absent; supratympanic fold barely visible, extending to just beyond level of axilla. Forelimbs slender, relative length of fingers $I < II < IV < III$; tips of all fingers with well-developed disks with distinct circummarginal grooves, disks relatively wide compared to finger width (third finger disk width 228% third finger width), disks slightly wider than long (third finger disk width 107% of length), third finger disk width 74% of tympanum diameter; webbing on fingers absent; dermal fringing absent; subarticular tubercles prominent, rounded, formula 1, 1, 2, 2; two palmar tubercles; accessory palmar tubercles present, small, distinct; prepollex with low tubercle; nuptial pad present on Finger I. Relative length of toes $I < II < III = V < IV$; tips of toes with well-developed disks with distinct circummarginal grooves; disks smaller than those of fingers; webbing formula $I2^{-} - 2^{+} III1^{1/2} - 3 III2^{-} - 3 IV2^{3/2} - 1^{1/2} V$; subarticular tubercles rounded, distinct, formula 1, 1, 2, 3, 2; inner metatarsal tubercle distinct, oval; outer metatarsal tubercle small, circular. Dorsal skin weakly rugose with sparsely scattered minute, pearly asperities; ventral surface of thighs and belly coarsely granular, chest and throat smooth. Dermal fringes and pointed projection at tibiotarsal articulation absent.

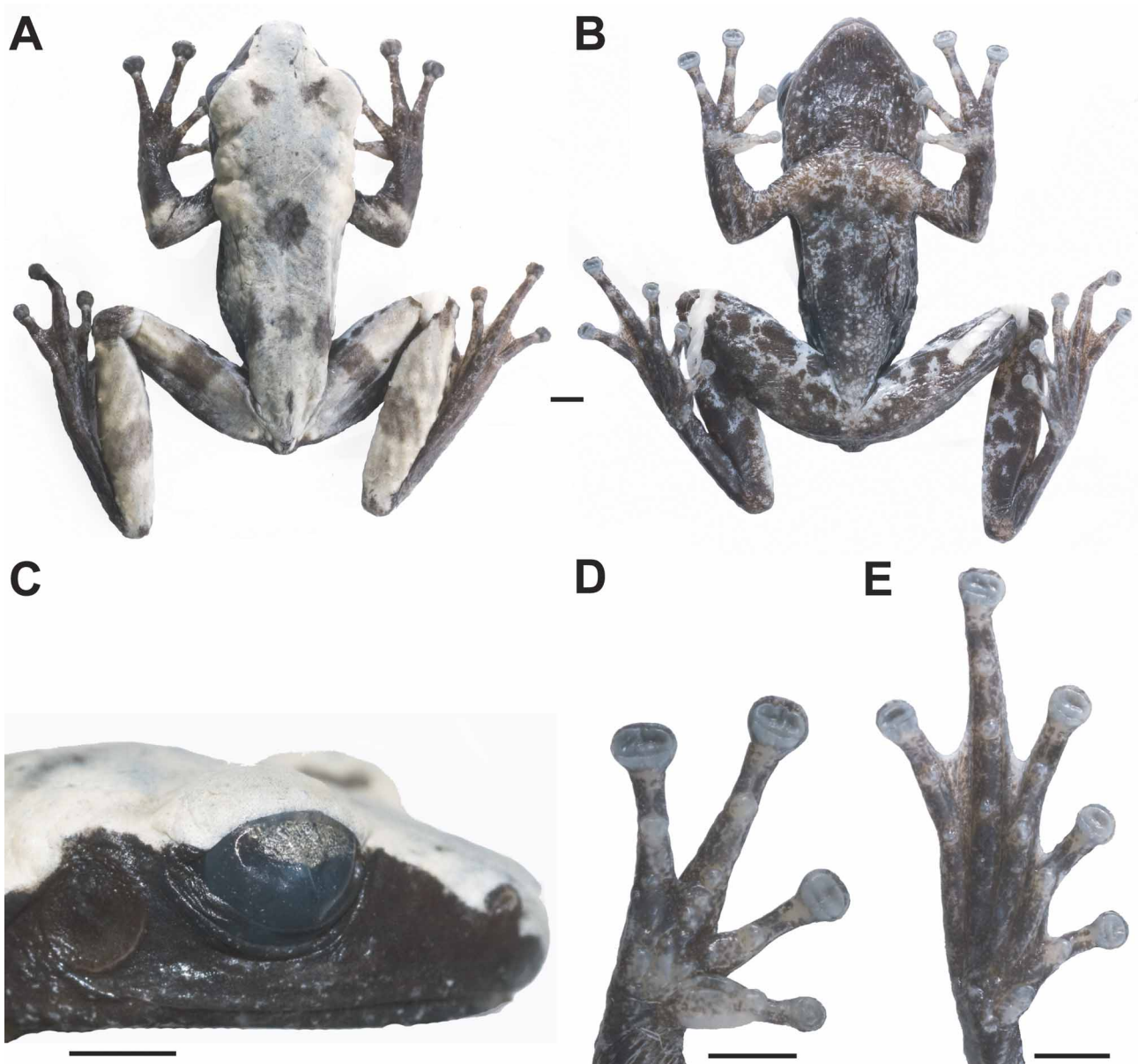


FIGURE 9. Adult male holotype of *Theloderma palliatum* sp. nov. (AMS R 173131) in preservative (A) Dorsal view, (B) ventral view, (C) lateral view of head, (D) ventral surface of right hand, and (E) ventral surface of right foot. Scale bars = 2 mm.

Colour of holotype in life. Dorsal surface pale coppery brown with distinct dark warm brown markings (Figure 8). Triangular inter-orbital blotches that abut the anterior edge of the inner margins of the orbital bulge, three

mid-dorsal blotches decreasing in size posteriorly; the largest 3.0 mm diameter, circular, approximately midway along back; middle blotch circular, 2.0 mm diameter; smallest blotch laterally compressed, approximately 1.5 mm x 0.4 mm. Single dark warm brown band running across ventral surface of tibiotarsus and thigh, and on to body to nearly join middle mid-dorsal blotch, approximately 2.5 mm wide; when leg is adpressed, forms a continuous line. Dark warm brown patches over heels and knees. Lateral surfaces dark warm brown, from tip of snout, through nare, under canthus rostralis, through eye, over tympanum and along sides of body. Dorsal surface of arms (except for elbows), hands and feet dark warm brown, the latter with faint white speckling. Ventral surfaces dark warm brown with pale bluish white marbling on chest, inguinal region, anterior surface of thighs and tibiotarsus. Faint white speckling on the throat and ventral surfaces of arms, extending laterally onto upper lip and flanks. Iris pale gold in upper third, and dark reddish brown in lower two-thirds; division of eye colour matches skin coloration adjacent to eye.

Colour of holotype in preservative. As in life, but base colour of dorsal surface fades to creamy white, and dark brown is slightly less warm in tone; overall specimens have a more contrasting pattern (Figure 9). The white marbling and speckling on ventral surface is also more distinct.

Variation. Measurements of the type series are shown in Table 2. As was noted for *T. licin* (McLeod & Norhayati 2007), and *T. nebulosum* **sp. nov.** (above), the new species has the ability to change colour over time. Upon capture (at night), the dark brown patterns were paler and background dorsal colour darker. The holotype (AMS R 173131) was a medium brown colour on the dorsal surface of head, extending along the back towards central mid-dorsal spot (Figure 8D). The distinct darker markings were still evident, but less distinct, and the dorsal surface of hands and feet were brownish grey. Diurnally, and in preservative, all specimens have nearly identical dorsal patterns and colours. Both the holotype (AMS R 173131) and adult male paratype (AMS R 173130) have distinct nuptial pads on Finger I.

Distribution and ecology. The new species is known only from montane evergreen forest above 1500 m at the type locality of Bidoup-Nui Ba National Park (Figure 10). During approximately 20 field surveys at the park between 2008–2010, only three specimens of *T. palliatum* **sp. nov.** were ever observed. Due to the small size and arboreal nature of these frogs, the apparent rarity of the species may be due simply to poor detectability.

Comparisons. The small body size, absence of vomerine teeth, presence of only minute dorsal asperities, no webbing on the hands, pale to medium brown dorsum with characteristic dark brown blotches and dark brown lateral surfaces extending from snout to groin, and a distinctly bicoloured iris distinguishes *T. palliatum* **sp. nov.** from all species of *Theلودerma* (Table 1). *Theلودerma palliatum* **sp. nov.** is most morphologically similar to the small *T. lateriticum*, *T. licin*, *T. rhododiscus* and *T. truongsponse* *comb. nov.* *Theلودerma palliatum* **sp. nov.** differs morphologically from *T. lateriticum* by having a pale to medium brown dorsum with dark brown dorsal markings (versus a dorsum with a deep brick-red wash overtop dark black-green, without the dark brown dorsal markings), dorsal tubercles the same colour as the dorsum (versus distinctly white tubercles on flanks and dorsal surface of limbs) and a distinctly bicoloured iris (versus uniformly deep brick red iris). From *T. licin*, *T. palliatum* **sp. nov.** differs by lacking webbing or fringing on hands (versus lateral dermal fringes and basal webbing on hands), having dark brown interorbital markings, bands across the tibiotarsus and patch on knee (versus no dark brown interorbital markings or bands across the tibiotarsus or knee), a distinctly bicoloured iris (versus uniformly red iris) and tuberculate as opposed to a smooth dorsum. From *T. rhododiscus*, *T. palliatum* **sp. nov.** differs by having the ventral surfaces of disks being brown to greyish brown (versus orange-red), and a distinctly bicoloured iris (versus uniformly reddish brown). From *T. truongsponse* *comb. nov.*, *T. palliatum* **sp. nov.** differs by having three, dark brown mid-dorsal spots (versus a single dark brown mid-dorsal spot), and a black/dark brown belly and ventral surface of thighs, with white/pale brown marbling (versus a grey belly and ventral surface of thighs with white spots). In addition, *Theلودerma palliatum* **sp. nov.** has an uncorrected sequence divergences at the 16S rRNA gene of >8.5% for all *Theلودerma* for which homologous 16S rRNA sequences are available.

Available names. Three available names are currently considered as junior synonyms of valid species names in the genus *Theلودerma*. These names need to be considered as possible earlier names for *T. nebulosum* **sp. nov.** and *T. palliatum* **sp. nov.** *Ixalus tuberculatus* (type locality Kakhyen Hills", Myanmar; Anderson 1879 "1878") is considered an invalid senior objective synonym of *T. andersoni* (Ahl 1927) (see Bossuyt & Dubois 2001). In the original description, *I. tuberculatus* was described as having a uniformly olive dorsum and yellowish chest and belly with very fine brown reticulations (compared to brownish dorsum and chest and belly dark brownish black with pale blue/white marbling in *T. nebulosum* **sp. nov.** and *T. palliatum* **sp. nov.**). *Philautus albopunctatus* (type

locality Yaoshan, Kwangsi, China; Liu & Hu 1962) is considered a junior synonym of *T. asperum* (Yu *et al.* 2007). The holotype of *P. albopunctatus* (adult male) is clearly referable to *T. asperum* in dorsal coloration, with large patches of white and dark brownish grey on dorsum in life (versus a brownish dorsum lacking white patches in both *T. nebulosum* **sp. nov.** and *T. palliatum* **sp. nov.**), and is 32.5 mm SVL (compared to < 30 mm SVL in *T. nebulosum* **sp. nov.** and *T. palliatum* **sp. nov.**). *Rhacophorus fruhstorferi* (type locality “Tonkin”, Vietnam; Ahl 1927) is considered a junior synonym of *T. corticale* (Wolf 1936), and is considerably larger than *T. nebulosum* **sp. nov.** and *T. palliatum* **sp. nov.** (69 mm SVL compared to <30 mm SVL in *T. nebulosum* **sp. nov.** and *T. palliatum* **sp. nov.**), and has a whitish throat (versus dark brown throat in *T. nebulosum* **sp. nov.** and *T. palliatum* **sp. nov.**).

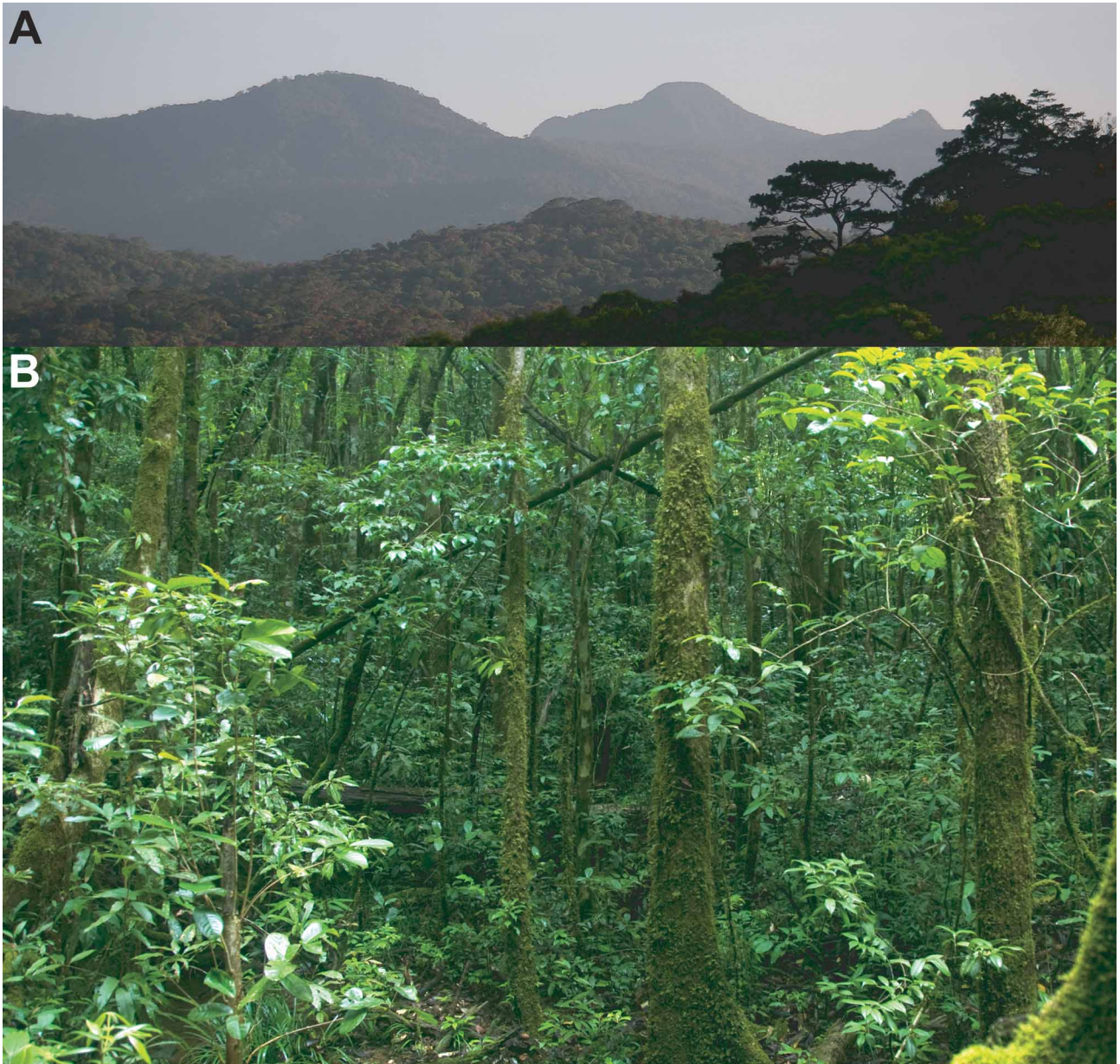


FIGURE 10. Habitat at type locality of *Theloderma palliatum* **sp. nov.** in Bidoup-Nui Ba National Park, Lam Dong Province, Vietnam.

Discussion

With the new species described here, and transfer of *T. truongsongense* comb. nov., a total of 20 species of *Theloderma* are now recognised (including *T. moloch*, for which correct generic allocation remains unresolved; Li *et al.*

2009). However, the assignment of any new species to the genus *Theلودerma* is complicated by the lack of a unique set of morphological characters defining the genus. A comprehensive revision of the rhacophoridae is required, including the genus *Theلودerma*.

The conservation status of the new species requires particular attention. The fauna of high elevation forests on the Kon Tum and the Langbian Plateaus is highly endemic (Abramov *et al.* 2006; Orlov 2005). Given the apparent high-elevation distribution and arboreal nature of the new species, they are likely to be restricted to relatively small patches of high-elevation forest on the Kon Tum (*T. nebulosum* sp. nov.) and Langbian (*T. palliatum* sp. nov.) plateaus, and hence particularly vulnerable to threatening processes such as habitat loss and over-collection. Habitat loss is not likely to be a major threat at the type localities of the new species, as they are both within protected areas, but is likely to impact upon the species outside of these areas. Collection for the international pet trade is perhaps more of an immediate threat, even in protected areas, as members of the genus are popular in captivity (Kunz *et al.* 2010), and at least one species within the genus is threatened by collection for the global pet trade (*T. corticale*; van Dijk & Bain 2004). We hope that the apparent rarity or low delectability of both new species may protect them from the threat of over-harvesting for the global pet trade.

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APPENDIX. Comparative material examined.

- Theloderma asperum*: Vietnam, Kon Tum Province, Ngoc Linh Nature Reserve (AMS R 173734, 173794).
- Theloderma bicolor*: Vietnam, Lao Cai Province (VNMN 1478).
- Theloderma gordonii*: Vietnam, Nghe An Province, Pu Hoat Proposed Nature Reserve (VNMN 03013).
- Theloderma stellatum*: Vietnam, Binh Thuan Province, Nui Ong Nature Reserve (AMS R 173283). Cambodia, Monduliri Province, Seima Biodiversity Conservation Area (AMS R 174047; tadpoles).
- Theloderma truongsongense* comb. nov.: Vietnam, Quang Nam Province, Song Thanh Nature Reserve (AMS R 171508, 171510).