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ZOOTAXA

A new species of karst forest-adapted Bent-toed Gecko (genus *Cyrtodactylus* Gray, 1827) belonging to the *C. sworderi* complex from a threatened karst forest in Perak, Peninsular Malaysia

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Abstract

A new species of Bent-toed Gecko *Cyrtodactylus guakanthanensis* **sp. nov.** of the *C. sworderi* complex is described from a limestone forest in Perak, Peninsular Malaysia whose karst formations at the type locality are within an active quarry. *Cyrtodactylus guakanthanensis* **sp. nov.** can be distinguished from all other Sundaland species by having the following suite of character states: adult SVL 77.7–82.2 mm; moderately sized, conical, weakly keeled, body tubercles; tubercles present on occiput, nape, and limbs, and extend posteriorly beyond base of tail; 37–44 ventral scales; no transversely enlarged, median, subcaudal scales; proximal subdigital lamellae transversely expanded; 19–21 subdigital lamellae on fourth toe; abrupt transition between posterior and ventral femoral scales; enlarged femoral scales; no femoral or precloacal pores; precloacal groove absent; wide, dark postorbital stripes from each eye extending posteriorly to the anterior margin of the shoulder region thence forming a transverse band across the anterior margin of the shoulder region; and body bearing five (rarely four) wide, bold, dark bands. Destruction of the karst microhabitat and surrounding limestone forest will extirpate this new species from the type locality and perhaps drive it to complete extinction given that it appears to be restricted to the particular microhabitat structure of the type locality and is not widely distributed throughout the karst formations. As with plants and invertebrates, limestone forests are proving to be significant areas of high herpetological endemism and should be afforded special conservation status rather than turned into cement.

Key words: new species, *Cyrtodactylus*, karst, limestone, conservation, biodiversity, Gua Kanthan, Peninsular Malaysia

Introduction

Karst forests compose some of the most unique microhabitats found in tropical ecosystems. They are generally open canopy forests surrounding formations of ancient limestone and comprised of a number of unique, small, spindly trees and spiny plants adapted to nutrient poor conditions and periodic drought (Kiew 1998). Despite the astonishing degree of floral endemism in karst forests, vertebrate systematists have generally overlooked these areas and thus, only a few specialized vertebrates are known to exploit the unique microhabitats they compose (i.e. Jenkins *et al.* 2004; Alström *et al.* 2010; Woxvold *et al.* 2009). The growing exception to this lack of scientific inquiry is the recent increase in the discovery of highly specialized, endemic species of reptiles found in Peninsular Malaysia. We have been surveying karst forests and their associated limestone formations since 2008 and have discovered seven new karst-adapted species of Rock Geckos (genus *Cnemaspis*: Grismer *et al.* 2008b, c, 2009,

2012a, 2013; Wood *et al.* 2013) with the description of an additional species in progress; two new species of karst-adapted Bent-toed Geckos (genus *Cyrtodactylus*: Grismer *et al.* 2012a) with two additional species descriptions in progress; and two new species of karst-adapted and karst forest-adapted snakes (Quah *et al.* in preparation). Remarkably, we have only explored approximately 2% of the known limestone formations and their associated karst forests (following Price 2001) and anticipate that tens of additional new species will eventually be discovered as exploration continues.

In this paper, we present the description of a new species of karst forest-adapted gekkonid lizard from the Gunung Kanthan limestone forest in Perak, Peninsular Malaysia (Fig. 1). This species bears the diagnostic traits that place it in the genus *Cyrtodactylus* (Grismer 2011a) as well as the diagnostic character states placing it within the *C. sworderi* complex (i.e., *C. sworderi* (Smith), *C. tebuensis* Grismer, Anuar, Muin, Quah, & Wood and *C. quadrivirgatus* Taylor; Grismer *et al.* 2013). However, this series of specimens manifests a unique suite of character states and a percent divergence based on the mitochondrial gene NADH dehydrogenase subunit 2 (ND2) that differentiate it from all other known species of *Cyrtodactylus* and a high degree of genetic divergence. The specific locality wherein these specimens were collected surrounds a massive limestone formation containing a huge cave known as Gua Kanthan (nicknamed "The Cathedral"). It is clearly the most striking feature in the Gunung Kanthan limestone forest and it harbors an endemic flora and fauna (Platnick *et al.* 1977; Wilson & Reeder 2005; Zhaoran *et al.* 2008). Unfortunately this is within an area that was leased by the Perak State Government and is scheduled to be quarried due to its high-value limestone content. We hope this description will bring attention to the high conservation value of limestone forests in general and to the Gunung Kanthan limestone forest in particular.
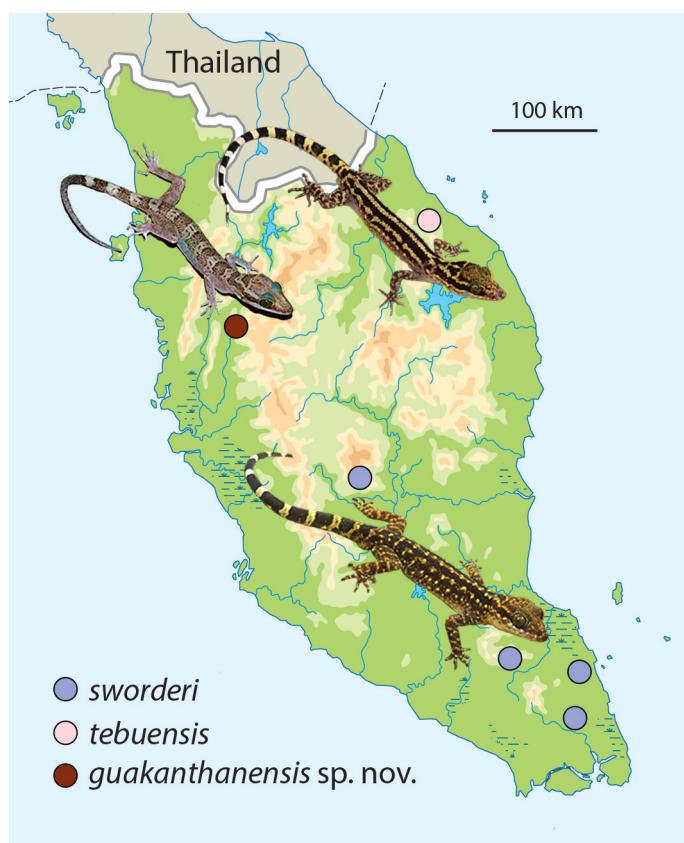

FIGURE 1. Distribution of the species of the *Cyrotdactylus sworderi* complex in Peninsular Malaysia. *Cyrtodactylus quadrivirgatus* was omitted owing to its ubiquitous distribution throughout Peninsular Malayisa (Grismer 2011a).

Material and methods

Morphological analysis. Color notes were taken using digital images of living specimens prior to preservation. The following measurements on the type series were taken with Mitutoyo dial calipers to the nearest 0.1 mm under

a Nikon SMZ 1500 dissecting microscope on the left side of the body where appropriate: snout-vent length (SVL), taken from the tip of snout to the vent; tail length (TL), taken from the vent to the tip of the tail, original or regenerated; tail width (TW), taken at the base of the tail immediately posterior to the postcloacal swelling; forearm length (FL), taken on the dorsal surface from the posterior margin of the elbow while flexed 90° to the inflection of the dorsiflexed wrist; tibia length (TBL), taken on the ventral surface from the posterior surface of the knee while flexed 90° to the base of the heel; axilla to groin length (AG), taken from the posterior margin of the forelimb at its insertion point on the body to the anterior margin of the hind limb at its insertion point on the body; head length (HL), the distance from the posterior margin of the retroarticular process of the lower jaw to the tip of the snout; head width (HW), measured at the angle of the jaws; head depth (HD), the maximum height of head from the occiput to the throat; eye diameter (ED), the greatest horizontal diameter of the eyeball; eye to ear distance (EE), measured from the anterior edge of the ear opening to the posterior edge of the eye ball; eye to snout distance (ES), measured from anteriormost margin of the eyeball to the tip of snout; eye to nostril distance (EN), measured from the anterior margin of the eye ball to the posterior margin of the external nares; interorbital distance (IO), measured between the anterior edges of the orbit; ear length (EL), the greatest horizontal distance of the ear opening; and internarial distance (IN), measured between the nares across the rostrum. Additional character states evaluated on the type series and comparative material (Appendix) were numbers of supralabial and infralabial scales counted from the largest scale immediately anterior to the dorsal inflection of the posterior portion of the upper jaw to the rostral and mental scales, respectively; the presence or absence of tubercles on the anterior margin of the forearm; the number of paravertebral tubercles between limb insertions counted in a straight line immediately left of the vertebral column starting at the midpoint between the forelimb insertions and ending at the midpoint between the hind limb insertions; the number of longitudinal rows of body tubercles counted transversely across the center of the dorsum from one ventrolateral fold to the other; the number of longitudinal rows of ventral scales counted transversely across the center of the abdomen from one ventrolateral fold to the other; the number of subdigital lamellae beneath the fourth toe counted from the base of the first phalanx to the claw; the total number of precloacal and femoral pores (*i.e.* the contiguous rows of femoral and precloacal scales bearing pores are combined as a single meristic); the presence or absence of a precloacal depression or groove; the degree and arrangement of body and tail tuberculation; the relative size and morphology of the subcaudal scales; the presence or absence of a white network of lines forming a reticulum on the top of the head; color pattern on body and nape (i.e., striped, banded, or blotched); degree of striping on the flanks and their degree of contact with a postorbital stripe; and the presence or absence of wide, dark bands on an original tail.

Some of the information on character states and their distribution in other species was obtained from De Rooij (1915), Smith (1930), Inger & King (1961), Taylor (1963), Dring (1979), Hikida (1990), Manthey & Grossman (1997), Das & Lim (2000), Grismer *et al.* (2008a); Rösler & Glaw (2008), and Chan & Norhayati (2010). Additional specimens examined are listed in the appendix. Institutional abbreviations follow Sabaj-Pérez (2010), except we retain ZRC (Zoological Reference Collection, Raffles Museum) for USDZ, following conventional usage. DWNP refers to the Department of Wildlife and National Parks Collection, Krau, Pahang, Malaysia; LSUHC refers to the La Sierra University Herpetological Collection, La Sierra University, Riverside, California, USA; and LSUDPC refers to the La Sierra University Digital Photo Collection.

Phylogenetic analysis. We obtained sequence data from a 1502 bp fragment of the mitochondrial NADH dehydrogenase subunit 2 (ND2) including the flanking tRNA's (Trp, Ala, Asn, Cys, Tyr) gene from two ingroup samples. Twenty-five additional ingroup samples based on Johnson *et al.* (2012), Grismer *et al.* (2012b), and outgroup samples based on Wood *et al.* (2012) were obtained from GenBank. All new sequences are deposited in GenBank XX00000–XX00000 (Table 1). Total genomic DNA was isolated from liver or skeletal muscle specimens stored in 95% ethanol using the Qiagen DNeasy™ tissue kit (Valencia, CA, USA). ND2 was amplified using a double-stranded Polymerase Chain Reaction (PCR) under the following conditions: 1.0 µl genomic DNA, 1.0 µl light strand primer 1.0 µl heavy strand primer, 1.0 µl dinucleotide pairs, 2.0 µl 5x buffer, MgCl 10x buffer, 0.1 µl Taq polymerase, and 7.56 µl ultra-pure H_2O (Table 2). PCR reactions were executed on an Eppendorf Mastercycler gradient theromocycler under the following conditions: initial denaturation at 95°C for 2 min, followed by a second denaturation at 95°C for 35 s, annealing at 47°C for 35 s, followed by a cycle extension at 72°C for 35 s, for 31 cycles. All PCR products were visualized on a 10 % agarose gel electrophoresis. Successful PCR products were vacuum purified using MANU 30 PCR plates (Millipore) and purified products were resuspended in ultra-pure water. Purified PCR products were sequence using the ABI Big-Dye Terminator v3.1

Cycle Sequencing Kit in an ABI GeneAmp PCR 9700 thermal cycler. Cycle sequencing reactions were purified with Sephadex G-50 Fine (GE Healthcare) and sequence on an ABI 3730xl DNA Analyzer are the BYU DNA Sequencing center. Primers used for amplification and sequencing are presented in Table 2.

TABLE 1. A list of the samples used in the molecular analyses with Genbank accession numbers. Abbreviated voucher numbers are as follows: LSUHC, La Sierra University Herpetological Collection, FMNH, Field Museum of Natural History, ZRC, Zoological Reference Collection, Raffles Museum.

Voucher	Species	Locality	ND2 GenBank Accession Numbers
LSUHC 8933	*C. batucolus*	West Malaysia, Melaka, Pulau Besar	JQ889178
LSUHC 8934	*C. batucolus*	West Malaysia, Melaka, Pulau Besar	JQ889179
LSUHC 6471	*C. elok*	West Malaysia, Pahang, Fraser's Hill, the Gap	JQ889180
LSUHC 11322	*C. guakanthanensis*	West Malaysia, Perak, Gua Kanthan	XXXXXX
LSUHC 11323	*C. guakanthanensis*	West Malaysia, Perak, Gua Kanthan	XXXXXX
FMNH 255454	*C. interdigitalis*	Lao PDR, Khammouan Province, Nakai District	JQ889181
FMNH 265812	*C. intermedius*	Thailand, Sa Kaeo, Muang Sa Kaeo	JQ889182
LSUHC 9513	*C. intermedius*	Thailand, Chantaburi Province	JQ889183
LSUHC 9514	*C. intermedius*	Thailand, Chantaburi Province	JQ889184
ZRC 2.6951	*C. majulah*	Nee Soon Swamp, Singapore	XX000000
ZRC 2.6952	*C. majulah*	Nee Soon Swamp, Singapore	XX000000
LSUHC 8906	*C. pantiensis*	West Malaysia, Johor, Gunung Panti FR, Bunker Trail	JQ889185
LSUHC 8905	*C. pantiensis*	West Malaysia, Johor, Gunung Panti FR, Bunker Trail	JQ889186
LSUHC 10070	*C. payacola*	West Malaysia, Penang, Bukit Panchor	JQ889190
LSUHC 10071	*C. payacola*	West Malaysia, Penang, Bukit Panchor	JQ889191
LSUHC 9982	*C. payacola*	West Malaysia, Penang, Bukit Panchor	JQ889192
LSUHC 5633	*C. quadrivirgatus*	West Malaysia, Perak, Temengor, PITC Logging Camp	JQ889204
LSUHC 5640	*C. quadrivirgatus*	West Malaysia, Perak, Temengor, PITC Logging Camp	JQ889206
LSUHC 8900	*C. semenanjungensis*	West Malaysia, Johor, Gunung Panti FR, Bunker Trail	JQ889177
LSUHC 6349	*C. seribuatensis*	West Malaysia, Johor, Pulau Nangka Kecil	JQ889187
LSUHC 7685	*C. sworderi*	West Malaysia, Johor, Endau-Rompin, Peta, Sungai Kawal	JQ889189
LSUHC 10902	*C. tebuensis*	West Malaysia, Terengganu, Gunung Tebu	JX988257
LSUHC 10852	*C. tebuensis*	West Malaysia, Terengganu, Gunung Tebu	JX988525
LSUHC 10851	*C. tebuensis*	West Malaysia, Terengganu, Gunung Teb	JX988524
LSUHC 10903	*C. tebuensis*	West Malaysia, Terengganu, Gunung Tebu	JX988528

TABLE 2. Primer sequences used in this study for the ND2 gene.

Primer name	Primer reference		Sequence
L4437b	(Macey *et al.*, 1997)	External	5'-AAGCAGTTGGGCCCATACC-3'
CyrtintF1	(Siler *et al.*, 2010)	Internal	5'-TAGCCYTCTCYTCYATYGCCC-3'
CyrtintR1	(Siler *et al.*, 2010)	Internal	5'-ATTGTKAGDGTRGCYAGGSTKGG-3'
H5934	(Macey *et al.*, 1997)	External	5'- AGRGTGCCAATGTCTTTGTGRTT-3'

For the phylogenetic analyses we applied two model-based methods, Maximum Likelihood (ML) and Bayesian Inference (BI). The Akaine Information Criterion (AIC) as implemented in ModelTest v3.7 (Posada & Crandall 1998) was used to calculate the best-fit model of evolution for each codon position (Table 3). Maximum Parsimony (MP) criteria and bootstrap estimates for nodal support was employed in PAUP* v4.0 (Swofford 2002).

One thousand bootstrap replicates for each heuristic search was run with ten random additional sequence replicates using tree bisection and reconnection (TBR) branch swapping. The 1000 bootstrap replicates were summarized as a 50% majority rule consensus tree. Maximum Likelihood analysis was performed using RAxML HPC v7.5.4 (Stamatakis *et al.* 2008), 1000 bootstrap pseudoreplicates via the rapid hill-climbing algorithm (Stamatakis *et al.* 2008). The Bayesian analysis was carried out in MrBayes v3.2 (Ronquist *et a.* 2012; Ronquist & Huelsenbeck 2003) using default priors. Two simultaneous runs were performed with eight chains per run, seven hot and one cold following default priors. The analysis was run for 5,000,000 generations and sampled every 500 generations from the Markov Chain Monte Carlo (MCMC). The analysis was halted after the average standard deviation split frequency was below 0.01. The program Are We There Yet? (AWTY) (Nylander *et al.* 2008) was employed to plot the log likelihood scores against the number of generations to assess convergence and to determine the appropriate number of burnin trees. We conservatively discarded the first 25% of the trees as burnin. A consensus tree was then computed from the two parallel runs using TreeAnnotator v1.6.1 (Drummond & Rambaut 2007). Nodes that had posterior probabilities above 0.95 were considered significantly supported.

Specimens examined as comparative material are listed in the appendices of Grismer *et al.* (2013). LSUHC refers to the La Sierra University Herpetological Collection, La Sierra University, Riverside, California, USA and LSUDCP refers to the La Sierra University Digital Photo Collection at the same address.

TABLE 3. Selected models of evolution estimated by the AIC implemented in Model test v3.7 (Posada & Crandall, 1998). Selected models were applied when applicable and the next complex model was used in the selected model could not be applied due to computer programing limitations.

Gene	Model selected	Model applied
ND2		
1st pos	GTR+I+Γ	GTR+I+Γ
2nd pos	GTR+I	GTR+I
3rd pos	GTR+Γ	GTR+Γ
tRNAs	HKY+Γ	HKY+Γ
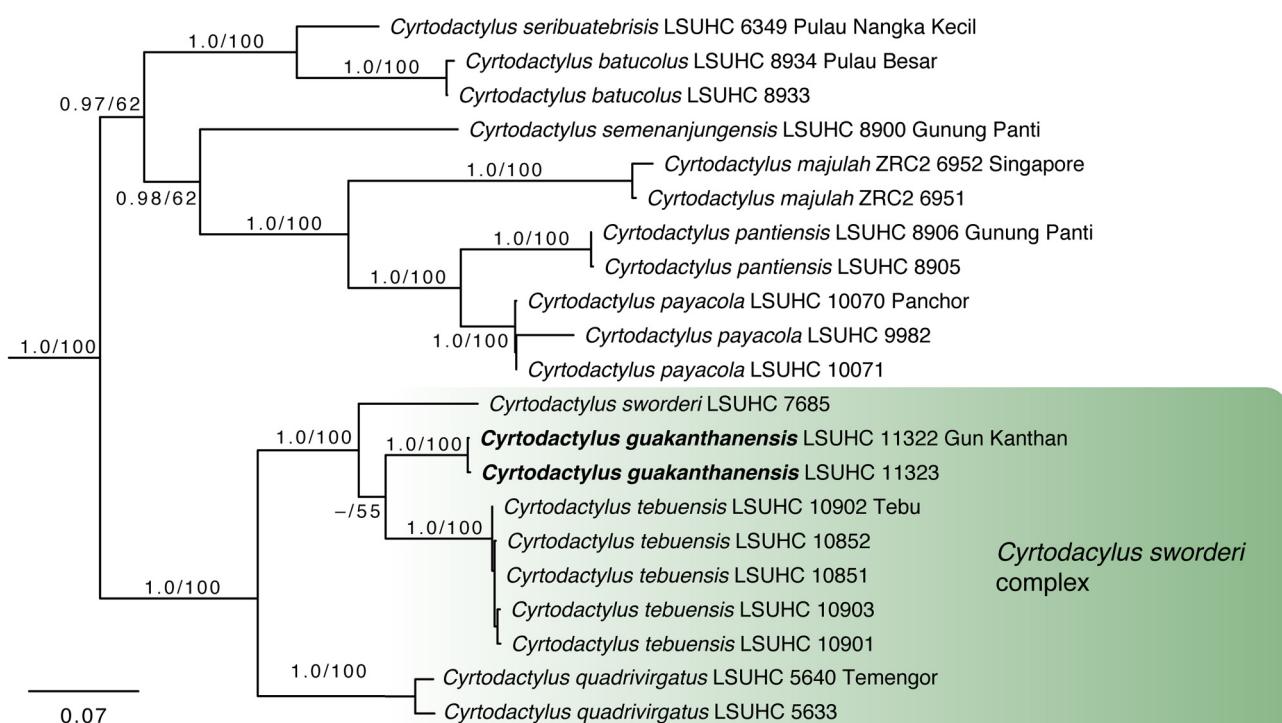
FIGURE 2. Inferred phylogenetic relationships of the *Cyrtodactylys sworderi* complex based on 1502 bp of mitochondrial ND2 gene. The tree is a Maximum Likelihood topology (lnL -13502.996020) with Bayesian posterior probabilities (BPP left) and Maximum Likelihood bootstrap support values (ML right).

Results

The molecular phylogeny indicates that the Gua Kanthan population is monophyletic group and nested within the *Cyrtodactylus sworderi* complex and within this complex it shows a closer relationship to *C. sworderi* and *C. tebuensis* than to *C. quadrivirgatus* (Fig. 2). Its sister species relationship with *C. tebuensis* was not recovered in the BI and had a low bootstrap value of only 55 in the ML analysis although this relation is suggested by their relatively close morphological similarity (Table 5). Additionally, the Gua Kanthan population has a sequence divergence from *C. tebuensis* of 10.7% and a divergence of 12.8% from *C. sworderi* (Table 4).

The morphological analysis indicates that the Gua Kanthan population can be differentiated from all other species of the *Cyrtodactylus sworderi* complex by having nine or 10 supralabials; seven or eight infralabials; 23–34 paravertebral tubercles; an abrupt transition between the large and small postfemoral scales; no femoral or precloacal pores; 36–41 enlarged femorocloacal scales; nine wide, light caudal bands; a banded dorsal pattern; and posterior contact of the postorbital stripes forming a band across the anterior margin of the shoulder region.

Based on the molecular and morphological data, it is clear the Gua Kanthan population would be considered a unique species under a general lineage species concept. Therefore we elect to describe it below as:

TABLE 4. Uncorrected p-distances for selecteds species of *Cyrtodactylus*.

	C. quakanthanensis	*C. batucolus*	*C. majulah*	*C. pantiensis*	*C. payacola*	*C. quadrivirgatus*	*C. semenanjungensis*	*C. seribuatensis*	*C. sworderi*
C. batucolus	0.219								
C. majulah	0.237	0.236							
C. pantiensis	0.226	0.229	0.183						
C. payacola	0.237	0.229	0.186	0.092					
C. quadrivirgatus	0.179	0.231	0.234	0.228	0.246				
C. semenanjungensis	0.226	0.208	0.223	0.218	0.231	0.231			
C. seribuatensis	0.220	0.108	0.229	0.218	0.214	0.234	0.197		
C. sworderi	0.128	0.222	0.238	0.223	0.246	0.180	0.233	0.217	
C. tebuensis	0.107	0.203	0.237	0.220	0.238	0.185	0.225	0.200	0.131

***Cyrtodactylus guakanthanensis* sp. nov.**
Gua Kanthan Bent-toed Gecko
Cicak Gua Kanthan
Figs 3, 4, 6

Holotype. Adult male (LSUHC 11322) from Gua Kanthan, Perak, Peninsular Malaysia (4°45.685'N, 101°07.322'E; 45 m) collected by Daicus M. Belabut, Chan K. Onn, Evan S. H. Quah and L. Lee Grismer on 14 July 2013.

Paratypes. All paratypes (LSUHC 11321, 11323, 11325–36, 11339) bear the same data as the holotype.

Diagnosis. *Cyrtodactylus guakanthanensis* **sp. nov.** can be distinguished from all other Sundaland species by having the following suite of character states: adult SVL 77.7–82.2 mm adult SVL; moderately sized, conical, weakly keeled, body tubercles; tubercles present on occiput, nape, and limbs, and extend posteriorly beyond base of tail; 37–44 ventral scales; no transversely enlarged, median, subcaudal scales; proximal subdigital lamellae transversely expanded; 19–21 subdigital lamellae on fourth toe; abrupt transition between posterior and ventral femoral scales; enlarged femoral scales; no femoral or precloacal pores; precloacal groove absent; wide, dark postorbital stripes from each eye extending posteriorly to the anterior margin of the shoulder region thence forming

a transverse band across the anterior margin of the forelimbs; and body bearing five (rarely four) wide, bold, dark bands. The meristic characters are scored against *C. sworderi*, *C. tebuensis* and *C. quadrivirgatus* in Table 5 and against all other Sundaland species in Grismer *et al.* (2012b: Table 5).

TABLE 5. Diagnostic characters (in bold) separating the species of the *C. sworderi* complex from *Cyrtodactylus guakanthanensis* **sp. nov.**

	guakanthanensis **sp. nov.**	*tebuensis*	*sworderi*	*quadrivirgatus*
Supralabials	9,10	**11–13**	10–13	8–11
infralaials	7,8	8–10	10	8–11
No. of paravertebral tubercles	32–34	32–39	**36–38**	32–39
No. of ventral scales	37–44	43–51	40–49	28–40
Postfemoral scale transition abrupt	yes	yes	**no**	**no**
No. of 4th toe lamella	19–21	17–21	16–20	18–23
Precloacal and /or femoral pores	absent	absent	**present**	**variable**
No. of precloacal pores	0	0	**5–9**	**0–12**
No. of enlarged femorocloacal scales	36–41	31–37	**0**	31–44
Light caudal bands	wide	**narrow**	**narrow**	wide
No. light bands on original tail	9	**10–14**	9–15	9–15
Dorsal pattern	banded	**Striped/spotted**	spotted	**variable**

=

Description. Adult male SVL 79.7 mm; head large, moderate in length (HL/SVL 0.29) and width (HW/HL 0.65), somewhat depressed (HD/HL 0.40), distinct from neck, and triangular in dorsal profile; lores weakly inflated, prefrontal region slightly concave; canthus rostralis smoothly rounded; snout elongate (ES/HL 0.44) and rounded in dorsal profile; eye large (ED/HL 0.22); ear opening elliptical and small (EL/HL 0.09); eye-to-ear distance greater than diameter of eye; rostral subrectangular with a deep dorsomedial furrow containing a postrostral; rostral partially divided dorsally, bordered posteriorly by large left and right supranasals, one large medial postrostral (=internasal) and one small azygous postrostral; external nares bordered anteriorly by rostral, dorsally by two supranasals (anterior one largest), posteriorly by five postnasals and ventrally by first supralabial; nine (R, L) square to rectangular supralabials extending to and tapering smoothly below posterior margin of orbit; eight (R), seven (L) infralabials tapering smoothly posteriorly to below posterior margin of orbit; scales of rostrum, lores, top of head, and occiput small and granular; scales on top of occiput intermixed with slightly enlarged tubercles; dorsal and ventral superciliaries rectangular; mental triangular, bordered laterally by first infralabials and posteriorly by left and right rectangular postmentals contacting medially for approximately 50% of their length posterior to mental; one enlarged row of sublabials extending posteriorly to 4th or 5th infralabial; gular scales small and raised, grading posteriorly into slightly larger, flatter, throat scales, and thence into large, flat, imbricate pectoral and ventral scales.

FIGURE 3. Upper: adult male holotype of *Cyrtodactylus guakanthanensis* **sp. nov.** (LSUHC 11322) from Gua Kanthan, Perak, Peninsular Malaysia. Middle: adult male paratype of *C. guakanthanensis* **sp. nov.** (LSUHC 11322). Lower: hatchling *C. guakanthanensis* **sp. nov.** (LSUDPC 8175)

FIGURE 4. Habitat at the type locality, Gua Kanthan, Perak, Peninsular Malaysia. Upper: eroded and cracked limestone wall that provides refuge for *Cyrtodactylus guakanthanensis* **sp. nov.** Lower: structure of the limestone forest of the type locality.

Body relatively short (AG/SVL 0.42) with weak, tuberculate ventrolateral folds; dorsal scales small and granular, interspersed with larger, conical, semi-regularly arranged, weakly keeled tubercles; tubercles extending from occiput to anterior one-third of tail; tubercles on occiput and nape relatively small, those on body largest; approximately 17 longitudinal rows of dorsal tubercles and 32 paravertebral tubercles; 37 flat, imbricate ventrals, ventrals much larger than dorsals; patch of enlarged precloacal scales lacking pores; precloacal groove absent.

Forelimbs moderate in stature, relatively short (FL/SVL 0.17); granular scales of forearm larger than those of body and interspersed with small tubercles; palmar scales rounded; digits well-developed, inflected at basal interphalangeal joints; subdigital lamellae slightly enlarged proximal to joint inflections, digits narrower distal to joints; claws well-developed, sheathed by a dorsal and ventral scale.

Hind limbs more robust than forelimbs, moderate in length (TBL/SVL 0.18), covered dorsally by granular scales interspersed with larger tubercles and anteriorly by granular scales; ventral scales of femora flat and larger than dorsals; ventral tibial scales flat and imbricate; a single row of enlarged femoral scales extend medially from proximal region of femur making contact with large precloacal scales; this enlarged row is bordered anteriorly by two rows of slightly smaller scales; femoral pores absent; dorsal and ventral femoral scales meeting abruptly on posteroventral margin of thigh; plantar scales low and slightly rounded; digits well-developed, inflected at basal interphalangeal joints; subdigital lamellae enlarged proximal to inflected joints, digits narrower distal to joints; 20 (L,R) subdigital lamellae on 4th toe; claws well-developed, sheathed by a dorsal and ventral scale.

Original tail widest at base, tapering to a point, approximately last one-fifth of tail missing; dorsal scales on base of tail granular, becoming flatter posteriorly; no median row of transversely enlarged subcaudal scales; caudal scales arranged in semi-whorls; three enlarged tubercles on both sides of base of tail; base of tail bearing lateral, bulbous swellings; all postcloacal scales moderately sized, flat, and imbricate.

Coloration in life (Fig. 3). Ground color of head, body, limbs and anterior portion of tail beige; snout and top of head brown bearing darker mottling; wide, dark brown postorbital stripes from each eye extend posteriorly to the anterior margin of the shoulder region, thence connecting medially and forming a transverse band across the base of the anterior margin of the forelimbs; single wide dark brown chevron-shaped marking on nape and base of occiput; four wide, dark brown body bands between limb insertions that extend laterally one-half way down flanks; single wide, dark brown sacral band; five dark caudal bands becoming darker and wider posteriorly; dorsal surface of limbs beige bearing darker mottling; ventral surface of head, body, and limbs immaculate off-white except for fine black stippling in scales; subcaudal region nearly black with six light bands encircling tail.

Variation. The paratypes closely resemble the holotype in all aspects of coloration and pattern (Fig. 3). The body bands in LSUHC 11325–26, and 11339 are oblique as opposed to being transverse. The regenerated tails of LSUHC 11321, 11323, 11326, and 11339 are mottled and lack banding. Hatchlings and juveniles (LSUDPC 8175–79) are more boldly marked, having a nearly immaculate ground color and generally darker bands and the posterior one-third of the tail is white (Fig. 3)—a character noted in other karst-dwelling species of *Cyrtodactylus* (Grismer *et al.* 2012a). Meristic variation is presented in Table 6.

Distribution. Currently, *Cyrtodactylus guakanthanensis* **sp. nov.** is known only from the type locality of Gua Kanthan in the Gunung Kanthan limestone forest, Perak, Peninsular Malaysia (Fig. 1).

Natural history. All lizards specimens were active at night on the limestone walls, adjacent boulders surrounded by limestone forest, and the limestone forest vegetation. Lizards only occurred in areas where cliff faces were eroded and exfoliated, providing cracks and holes in which to take refuge during the day (Fig. 4). No lizards were found in areas where the cliff faces were smooth and bearing no surface irregularities. Many of the specimens observed were found in the adjacent vegetation between 0.5–4 m above the ground on the trunks of trees or on vertical and horizontal branches and vines, indicating that the surrounding forest itself is an integral part of this new species' habitat preference. One specimen was observed deep within the cave where vegetation was absent. Hatchlings as small as 33.8 mm SVL (LSUDPC 8175; Fig. 3) were observed but no gravid females were found, suggesting that the reproductive season occurred in July.

Etymology. The specific epithet *guakanthanensis* is an adjective and refers to the type locality Gua Kanthan (=Kanthan Cave) within the Gunung Kanthan limestone forest.

Comparisons. Within the *Cyrotdactylus sworderi* complex, *C. guakanthanensis* is separated from *C. quadrivirgatus* by having an abrupt transition between small and large postfemoral scales and a banded dorsal pattern. From *C. sworderi* it differs in having fewer paravertebral tubercles (32–34 versus 36–38); lacking as opposed to having precloacal pores; having as opposed to lacking enlarged femoral scales; having wide as opposed

to narrow whitish caudal bands (Fig. 1); and having a banded as opposed to spotted dorsal pattern (Fig. 1). It differs from *C. tebuensis* in potentially having few suprlabials (nine or 10 versus 11–13); having wide as opposed to narrow whitish caudal bands which are fewer in number (nine versus 10–14; Fig. 1); and having a banded versus a spotted or striped dorsal pattern (Fig. 1). These differences are compared between all members of the *C. sworderi* complex in Table 5.

TABLE 6. Morphological characters of type series of *Cyrtodactylus guakanthanensis* **sp. nov.** /=data unavailable.

	LSUHC 11321 paratype	LSUHC 11322 holotype	LSUHC 11323 paratype	LSUHC 11325 paratype	LSUHC 11326 paratype	LSUHC 11339 paratype
sex	f	m	m	m	m	m
supralabials	10	9	10	9	10	10
infralabials	7	8	8	8	8	7
No. of paravertebral tubercles	34	32	33	32	33	33
No. of ventral scales	44	37	42	42	41	38
4th toe lamellae	21	20	20	21	21	19
Preclacal pores present (1) or absent (0)	0	0	0	0	0	0
No. of enlarged femorocloacal scales	37	39	36	41	39	36
No. of light bands on original tail	/	/	/	9	/	/
No. of body bands	5	4	5	5	5	5
SVL	82.2	79.7	79.8	78.2	77.7	81.8
TL	91.5	78.3	83.4	97.9	85.7	89.2
TW	7	7.4	7.3	7.1	7.2	6.8
FL	12.9	13.3	13	13.2	12.6	12.7
TBL	14.7	14.7	15.5	15.4	14.5	16
AG	36.2	33.3	34.1	35	34.5	37.8
HL	23	22.3	22.8	22	21.3	23
HW	15.1	14.5	15.1	15	13.3	15.1
HD	9.5	9	9.6	9.5	8.3	9.7
DE	5.5	5	5.5	5.2	4.7	5.6
EE	6.5	6.3	6.2	6.3	5.8	6.5
ES	9.9	9.8	10	10.1	10.1	10.2
EN	7.8	7.5	7.6	7.6	7.5	7.8
IO	4.2	3.9	4.2	3.8	3.8	4
EL	1.7	1.9	1.7	2.3	1.5	1.9
IN	2.5	2.6	2.5	2.4	2.4	2.4

Discussion

The Gunung Kanthan limestone forest surrounds 400 million year old limestone formations that harbor a number of unique plants and animals. Owing to the purity of its limestone, the area is scheduled to be quarried. Our data indicate that *Cyrtodactylus guakanthanensis* **sp. nov.** does not range continuously throughout the limestone forest but appears to be restricted to areas that have an eroded complex limestone microhabitat. One of the quarry zones targeted is Gua Kanthan, the type locality of *C. guakanthanensis* **sp. nov.** Grinding down the limestone in this area and cutting the surrounding forest will destroy the microhabitat to which this new species has adapted and our data indicate this species may not occur elsewhere.

The discovery of *Cyrtodactylus guakanthanensis* **sp. nov.** adds to a growing body of evidence that karst regions should be protected and better studied. If reptiles are an indication of the hidden diversity within these unique habitats, then limestone forests may be some of the most biotically rich habitats in Peninsular Malaysia with a level of herpetological endemism approaching that of Malaysia's islands (see Chan *et al.* 2010; Grismer 2008, 2011b; Grismer *et al.* 2011). Terminating this species before it is discovered, described, and studied is not only illogical, it is tantamount to discarding a wrapped gift before it is opened and its value assessed.

Acknowledgements

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