Taxonomic Studies of Bent-Toed Geckos of the Genus *Cyrtodactylus* Gray, 1827 from Borneo

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List of Abbreviations

A-G: axilla to groin

EarL: maximum ear length

et al.: and others

FAL: forearm length

FemPores: total femoral pores

Fin4L: length of the fourth finger

Fin4Lam: lamellae under fourth finger

HD: maximum head depth

HL: head length

HW: maximum head width

ID: Indraneil Das

IL: number of infralabials

IO: interorbital, minimum of frontal

JW: jaw width at posterior axis of lower and upper mandible

MBTR: mid-body tubercles rows

mm: millimeter

MOS: Mona

MVSR: mid-ventral scales

OrbD: horizontal orbit diameter

Orbear: orbit to ear distance

OrbSn: orbit to snout distance

P: Pui

PrePores: total pre-anal pores

SL: number of supralabials on the right and left

SUBC: Subcaudals- scales under tail

SVL: snout-vent length

TbL: tibia length

TD: maximum tail depth

Toe4L: length of the fourth toe

Toe4Lam: lamellae under fourth toe

TTL: total tail length

TW: total tail width

YR: Yugees Rao

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ABSTRACT

The study focused on the genus *Cyrtodactylus* Gray, 1827 belonging to the family Gekkonidae in Borneo. Borneo houses 10 species of this genus, including one which is undescribed. Those nine named species are: *C. consobrinus*, *C. pubisulcus*, *C. baluensis*, *C. yoshii*, *C. ingeri*, *C. matsuii*, *C. cavernicolus*, *C. quadrivirgatus* and *C. malayanus*. The objective of the study was to determine the differences and relationships among the species of the genus *Cyrtodactylus* known from Borneo in terms of morphology and colouration patterns and to provide a descriptive account of their morphology. The result of cluster analysis in this study revealed that the members of the genus *Cyrtodactylus* could not be separated into distinguishable groups because of small sample size and overlapping morphological characters. The discriminant function (DFA) analysis showed that the only character that could be used to distinguish between members of Bornean *Cyrtodactylus* is subcaudal count. A taxonomic key was constructed as a result of this study to discriminate and identify individual species.

Key words: Gekkonidae, *Cyrtodactylus*, Borneo, descriptive morphology, taxonomic key.

ABSTRAK

Kajian ini fokus pada genus Cyrtodactylus *Gray, 1827 dari famili Gekkonidae di Borneo. Borneo mempunyai 10 spesis dari genus ini termasuk satu spesies yang belum dinamakan secara khas. Sembilan spesis tersebut adalah* C. consobrinus, C. pubisulcus, C. baluensis, C. yoshii, C. ingeri, C. matsuii, C. cavernicolus, C. quadrivirgatus *dan* C. malayanus. *Tujuan kajian ini adalah untuk menentukan perbezaan dan hubungan di antara spesis dari genus Cyrtodactylus dari Borneo, dari segi morfologi dan pewarnaan dan juga untuk memberikan deskripsi terperinci tentang morfologi. Keputusan analisis cluster menunjukkan bahawa ahli-ahli genus* Cyrtodactylus *tidak dapat dibahagikan kepada kumpulan yang berasingan berdasarkan morfologi kerana saiz sampel yang kecil dan karakter-karakter morfologi yang bertindih antara satu sama lain. Hasil keputusan analisis diskriminan funsi menunjukkan bahawa satu-satunya karakter yang dapat membezakan antara ahli-ahli genus* Cyrtodactylus *adalah subkaudal. Sebagai hasil kajian, sebuah kunci taksonomi telah dibina untuk diskriminasi dan pengenalan spesies secara individu.*

Kata kunci: Gekkonidae, Cyrtodactylus, *Borneo, deskripsi morfologi, kunci taksonomi.*

1.0 INTRODUCTION

Borneo, the largest island of Malay Archipelago and third largest in the world, is situated in the coordinates of 04°S-07°N and from 109°-119°E and it is said to be rich in biodiversity throughout its tropical forests (Borneo, 2008). The major part of the island comprises of Kalimantan, in a size of 539,460 km^2, followed by Sarawak (124,450 km^2), Sabah (73,710 km^2) and Sultanate of Brunei Darussalam (5,760 km^2) (Borneo, 2008).

From the considerable amount of biodiversity that has been recorded from the island of Borneo, reptiles are represented by 289 species including 158 are snakes, 109 are lizards, 19 turtles and three crocodile species (Das, 2006).

The members of family Gekkonidae are the most successful group by their number of species numbering approximately 850 worldwide. The members of this family are widely distributed throughout all continents from tropical and sub-tropical parts of the world to significant numbers of oceanic islands and several temperate zones (Zug, 1993).

The members of Gekkonidae are also known as the true geckos and are the most primitive group of living lizards. The gekkonids are terrestrial to arboreal, having various number of body shapes. The body shapes of the geckos vary from broad-headed to robust-bodied and their limbs are from slender, elongate to some nearly limbless (Zug, 1993).

The members of family Gekkonidae are mostly nocturnal, occasionally seen basking in the late afternoons (Zug, 1993). Some species are strictly diurnal and easily noticeable due to their bright colours. All the species of this family are primarily known as insectivorous, feeding on flies, mosquitoes and cockroaches. The tails of these geckos are detachable, as the one lost being replaced (Das, 2006).

The family Gekkonidae is subdivided into two major groups, the Gekkoninae and Pygopodinae. The genus *Cyrtodactylus* Gray, 1827 belongs to the subfamily Gekkoninae.

Globally, there are at least 115 described species in the genus *Cyrtodactylus* with many new species being described annually, which makes it one of the most speciose rich genera in this family (Sumontha *et al.*, 2010).

Bauer (2003) and Oliver *et al.* (2008) indicated that the genus *Cyrtodactylus* is a large, geographically cohesive and probably non-monophyletic genus. The members of this genus are widely distributed from South and East Asia to northern Australia and western Melanesia (Kraus, 2007).

These geckos are typically medium-sized geckos and they are nocturnal and according to Chan and Norhayati (2010), the members of the genus *Cyrtodactylus* Gray, 1827 are terrestrial to scansorial forest-dwelling with slender and inflected digits and their limbs are long. The occurrence and biology of *Cyrtodactylus* are poorly documented due to their habitats which are usually primary forests (Sumontha *et al.*, 2010).

Borneo is home to 10 out of the 115 species, in which nine are described and one is currently being described. They are Peters' bent-toed gecko, *Cyrtodactylus consobrinus* Peters, 1871; grooved bent-toed gecko, *C. pubisulcus* Inger, 1957; Kinabalu bent-toed gecko, *C. baluensis* Mocquard, 1890; Yoshi's bent-toed gecko, *C. yoshii* Hikida, 1990; Inger's bent-toed gecko, *C. ingeri* Inger, 1958; Matsui's bent-toed gecko, *C. matsuii* Hikida, 1990; Niah bent-toed gecko, *C. cavernicolus* Inger and King, 1961; four-striped bent-toed gecko, *C. quadrivirgatus* Taylor, 1962 and Malayan bent-toed gecko, *C. malayanus* de Rooij, 1915 (Hikida, 1990; Rösler *et al.*, 2008; Das, 2010).

1.1 Objectives

- To determine the differences and relationships among the species of the genus *Cyrtodactylus* known from Borneo in terms of morphology and colouration patterns
- To provide details of descriptive morphology on all species using techniques of morphometrics.

2.0 LITERATURE REVIEW

There were few studies on the taxonomy and relationships among members of the geckos of the genus *Cyrtodactylus* Gray, 1827 in Borneo. However, a number of new species have been and currently being described in recent years from Borneo and adjacent areas.

2.1 Taxonomy

The genus *Cyrtodactylus* is a member of class Reptilia, order Squamata, suborder Sauria and family Gekkonidae (Das, 2006). The geckos of *Cyrtodactylus* are commonly known as "bent-toed geckos". They lack expanded toe pads and have slender fingers and thus, are regarded as having "bent-toed" appearances (Bauer, 2002).

David *et al.* (2004) remarked that the genus *Cyrtodactylus* is taxonomically challenging due to its limited morphological differences. Additionally, Bauer (2002) mentioned that the nomenclature of the genus is rather challenging as robust phylogenetic hypotheses at intergeneric and intrageneric levels are inadequate.

However, each species of *Cyrtodactylus* vary from one another and have their own characteristics for identification although sometimes they are confused with each other. Brown and Parker (1973) assured that the enlarged scales in the preanal region and femoral region or thighs can be used to distinguish species of *Cyrtodactylus* in the Philippines and Borneo.

Males and females of this genus can be distinguished by the presence of hemi-penal bulge, preanal pores, preanal groove or femoral pores in males where these characteristics are absent, not developed or indistinct in females and juveniles (Hikida,

1990). Mostly, juveniles of *Cyrtodactylus* resemble their parents but some times the juveniles might be confused with other species as they show some differences from adults in terms of colouration and colour patterns.

There are only few studies conducted on the taxonomy of the species of genus *Cyrtodactylus* and through primary findings, there is only one study in Borneo by Hikida (1990). According to Hikida (1990), *C. pubisulcus* and *C. cavernicolus* possess a preanal groove while *C. baluensis, C. consobrinus* and *C. malayanus* lack it.

Another study by Rösler and Glaw (2008) provided a literature survey on meristic and mensural data of all described species of *Cyrtodactylus*, including the Bornean species, and described a gecko specimen collected 100 years ago from Batang Padang, Perak.

In order to provide a taxonomic key for the Bornean *Cyrtodactylus*, Hikida (1990) included all the measurements of specimens useful in identifying species whereas Rösler and Glaw (2008) provided the summarized basic meristic and mensural data of all described species of *Cyrtodactylus* including the Bornean species.

2.2 Genus *Cyrtodactylus*

Genus *Cyrtodactylus* Gray, 1827 is said to be the most diverse group of the Gekkonidae lizards (Ziegler *et al.*, 2010). In Borneo, the genus *Cyrtodactylus* is composed of nine described and one undescribed species namely: Peters' bent-toed gecko, *Cyrtodactylus consobrinus* Peters, 1871; grooved bent-toed gecko, *C. pubisulcus* Inger, 1957; Kinabalu bent-toed gecko, *C. baluensis* Mocquard, 1890; Yoshi's bent-toed gecko, *C. yoshii* Hikida, 1990; Inger's bent-toed gecko, *C. ingeri* Inger, 1958; Matsui's bent-toed gecko, *C. matsuii* Hikida, 1990; Niah bent-toed gecko, *C. cavernicolus* Inger and King, 1961; four-striped bent-toed gecko, *C. quadrivirgatus* Taylor, 1962; Malayan bent-toed gecko, *C. malayanus* de Rooij, 1915 and *Cyrtodactylus* sp. (Hikida, 1990; Rösler *et al.* 2008; Das, 2010).

The members of this genus are distributed throughout the Indo-Australian Archipelago westward to India (Linkem *et al.*, 2008). New species of *Cyrtodactylus* continue to be described till date (Linkem *et al.*, 2008).

A study was carried out by Nazarov *et al.* (2008) provided a detail account of *C. irregularis* complex with the description of a new species from Dac Lac Province. They also stated about the variation of the *C. irregularis* complex forms.

2.3 Description of species

Descriptions of the following nine species were referred from Hikida (1990), Das (2004; 2006; 2010), Heidrich *et al.* (2007), Geissler *et al.* (2009) and McFarlane *et al.* (2009).

2.3.1 Peters' bent-toed gecko, *Cyrtodactylus consobrinus* Peters, 1871

The Peters' bent-toed gecko, *C. consobrinus* Peters, 1871 is a large gecko with an adult size of maximum snout vent length of 125 mm. The body is robust and has 18–29 midbody tubercles and 58–70 midventral scales. This species lacks preanal groove in both males and females but preanal pores of 9–10 are present in males while 9–14 preanal scales forming a narrow angular series present in both sexes. The supralabials and infralabials count range between 10–16 and 9–13, respectively. The dorsum of the adult gecko is dark chocolate brown with 4–8 yellow or white transverse bands. The juveniles are slightly different from their adults, where the head and dorsum are blackish–grey to jet–black in colour.

C. consobrinus is a forest gecko which is often associated with mature trees of lowland dipterocarp forests. It is a common arboreal species which can usually be found at night on tree trunks or stumps with crevices or holes.

2.3.2 Grooved bent-toed gecko, *C. pubisulcus* Inger, 1957

This is a small-sized gecko with slender body and a maximum snout vent length of 77mm. It is characterized by presence of preanal groove, preanal pores of 3–5 pairs, midventral scales between 43–55, midbody tubercles between 17–22, 10–11 supralabials and 17–22 subdigital lamellae. The tail to body ratio of *C. pubisulcus* is 1:1. The dorsum is

dark grey or brown in colour with dark cross bars or blotches which are sometimes arranged in longitudinal row.

C. pubisulcus is nocturnal and arboreal and sometimes occur syntopically with the *C. consobrinus*. This gecko is usually found on leaves, twigs, vines, small trees, logs and rocks.

2.3.3 Kinabalu bent-toed gecko, *C. baluensis* Mocquard, 1890

This gecko is medium-sized with slender body and maximum snout vent length of 86mm. Preanal groove is absent but preanal pores are 9–10 while femoral pores are 6–9. The midventral scales count is up to 45 and midbody tubercles count up to 24. The gecko also has supralabials of 10–12 and infralabials of 9–10. The lamellae under the fourth toe are 21–23. Dorsum is from brown to yellowish brown with rough dark spots or cross bands.

C. baluensis is a nocturnal species, commonly found foraging on leaves or sometimes on tree trunks, buttresses and forest clearings and tends to hide under loose bark and fallen trees during the day.

2.3.4 Yoshi's bent-toed gecko, *C. yoshii* Hikida, 1990

Hikida (1990) described this gecko as a robust, medium-sized which has an adult snout vent length of 75.2–96.2 mm. It does not possess preanal groove, enlarged preanal scales or femoral pores. It has 8–12 preanal pores forming a narrow angular series in a distinct groove. The fourth toe has subdigital lamellae counts of 25–30 but the lamellae are not widened. It has midventral scale count 50–58, midbody tubercles –17 in a row and supralabials 10–14. The dorsum is grey in colour with five V-shaped dark cross bars

linking nape and inguinal region, a dark brown V-shaped stripe extends from posterior corner of orbit.

Hikida (1990) mentioned that *C. yoshii* occurs in lowland forests from near sea level, up to 500 m above sea level. The gecko is seen on tree trunks or stumps at night and uses holes and crevices on tree trunks for shelter during daytime.

2.3.5 Inger's bent-toed gecko, *C. ingeri* Inger, 1958

This is a small-sized gecko with a slender body and snout-vent length to the maximum of 80.2mm. It lacks preanal groove and femoral pores. The preanal pores are 7–9 and form a narrow angular series of the gecko and it has 17 midbody tubercles in a row and midventral scales from 40 to 43. The supralabials and infralabials of this gecko are 10–12 and 8–10 respectively. There are 23–28 subdigital lamellae under the fourth toe of this gecko. The dorsum of the geckos is dark grey or yellowish brown and has 5–6 diamond shaped para-vertebral blotches, longitudinally arranged and are sometimes seen to be fused. Das (2006) mentioned that there is a dark stripe at posterior corner of eyes that inserts to the forearm.

This species is endemic to Borneo and resides in riparian forests, 500–800 m above sea level.

2.3.6 Matsui's bent-toed gecko, *C. matsuii* Hikida, 1990

C. matsuii is a large gecko with maximum snout-vent length of 105 mm, the body is stout, having midbody tubercles of 18 in a row and midventral scales of 48–51. This is another member of *Cyrtodactylus* which does not have preanal groove and femoral pores but possesses preanal pores of 7–8. The fourth toe has 22 subdigital lamellae, which are

widened. Dorsum of the gecko is yellowish brown and has dark cross bands on it while forehead show small dark spots on it. The posterior corner of the eyes of the gecko is joined by dark bands.

Das (2006) stated that the *C. matsuii* populates forests at elevation between 900 to 1600 m and mainly feeds on insects and other arthropods.

2.3.7 Niah bent-toed gecko, *C. cavernicolus* Inger and King, 1961

This is a cave-dwelling gecko which is endemic to Niah cave. It slender-bodied and medium-sized gecko with a maximum snout-vent length of 80.8 mm and have a tail to body ratio of 0.7. It has a preanal groove with four pores but do not have preanal or femoral scales. The midbody tubercles and midventral scales are 20–22 in a row and 51–58, respectively and subdigital lamellae are 22–26. The dorsum is brown with dark–edged cross–bars. It possesses a dark stripe from posterior end of eyes to nape.

A cave-dweller, it is found on the walls of the caves but occasionally juveniles are found under fallen trees on the forests floor. This is the only member of *Cyrtodactylus* in Borneo that is a Totally Protected Species in Sarawak and it is considered, the most vulnerable because of its small range.

2.3.8 Four-striped bent-toed gecko, *C. quadrivirgatus* Taylor, 1962

As its name suggests, this gecko is recognized by four black longitudinal stripes on its dorsum. With a slender body, it has a maximum snout-vent length of 71 mm, 10 supralabials, 10 infralabials and 40 midventral scales. The males of this gecko have four preanal pores but preanal groove is absent in both sexes. The dorsum is dark grey or dark

brown and has four black longitudinal lines which are separated by lighter areas. According to Das (2006), it inhabits both primary and secondary type forests.

2.3.9 Malayan bent-toed gecko, *C. malayanus* De Rooij, 1915

This Bornean endemic is a robust, medium-sized gecko with a maximum snout vent length of 117 mm and it lacks preanal groove, however, preanal pores are said to be indistinct in males. The midventral scales from 58 to 62 while the subdigital lamellae are from 21 to 23. The tail of this gecko has large subcaudals. The dorsum is chestnut brown and shows narrow light cross bars with isolated dark spots along the vertebral region.

Das (2004) stated that this species of gecko is nocturnal and arboreal and usually dwells on large trees in lowland dipterocarp forests.

2.3.10 Gunung Mulu bent-toed gecko, *Cyrtodactylus* sp.

This undescribed species, collected from Gunung Mulu, was previously confused with *C. cavernicolus* and is considered a Mulu endemic (McFarlane *et al.*, 2009). This new species of gecko is possibly a sister taxon to *C. cavernicolus* and it may have evolved independently to a troglophilic habit from a common ancestor. This species is currently being described by Prof. Dr. Indraneil Das and colleagues.

3.0 MATERIALS AND METHODS

3.1 Materials

The study was conducted in the Biodiversity and Systematic laboratory of Institute of Biodiversity and Environmental Conservation (IBEC), UNIMAS. Specimens used were collected in the past 10 years. Measurements were taken with digital caliper, and morphological observations made with an Olympus SZX9 stereomicroscope including the numbers of midbody tubercle rows and midventral scales. Specimens were preserved in 70% ethanol. Photographs of life geckos were used to extract data on colour patterns. Specimens used for the study were from the Biodiversity and Systematic Laboratory of Institute of Biodiversity and Environmental Conservation (IBEC) and the Raffles Museum for Biodiversity Research, National University of Singapore.

3.2 Methods

3.2.1 *Data Collection*

Measurements were made using a digital calliper to the nearest 0.1 mm and counting, observing and data recording in individual data sheets for every species. The following measurements were taken, following Mahony *et al.* (2009): snout-vent length (SVL), total tail length (TTL), total tail width (TW), maximum tail depth (TD), axilla to groin (A-G), forearm length (FAL), tibia length (TbL), maximum head width (HW), head length (HL), maximum head depth (HD), jaw width at posterior axis of lower and upper mandible (JW), horizontal orbit diameter (OrbD), inter-orbital, minimum of frontal (IO), orbit to snout distance (OrbSn), orbit to ear distance (Orbear), maximum ear length (EarL), total pre-cloacal / pre-anal pores (PrePores), femoral pores (FemPores), number of supralabials on the right and left (SL), number of infralabials (IL), midbody tubercles rows (MBTR), midventral scales (MVSR), length of the fourth finger (Fin4L), lamellae under fourth finger (Fin4Lam), length of the fourth toe (Toe4L), lamellae under fourth toe (Toe4Lam), TTLTW (ratio of total tail length to tail width), TTLTD (ratio of total tail length to tail depth), HWHL (ration of head width to head length) and HWHD (ration of head width to head depth). SUBC (subcaudals- scales under the tail) were observed and their presence or absence was recorded as well. Colouration patterns were observed and recorded as follows: no pattern (0), blotches (1), cross-bands / bars (2), and stripes (3). Each specimen was measured and details of morphology were recorded in individual data sheets.

3.2.2 *Data Analysis*

Statistical analyses were performed using SPSS, version 18. Cluster analysis was used to observe the grouping or clustering of species into individual groups. Hierarchical clustering technique was adopted as data is not partitioned into number of classes or clusters at a single step (Everitt, 1993). Discriminant function analysis (hereafter DFA) was used to separate two or more groups of individuals, given the measurements for these individuals on several variables (Manly, 1986).

For both analysis, 73 individuals were used: 16 individuals of *C. consobrinus*, 20 individuals of *C. pubisulcus*, six individuals of *C. ingeri*, three individuals of *C. malayanus*, four individuals of *C. matsuii*, two individuals of *C. yoshii*, seven individuals of *C. quadrivirgatus*, eight individuals of *C. baluensis*, two individuals of *C. cavernicolus* and three individuals of *Cyrtodactylus* sp.

3.2.2.1 *Hierarchical Clustering Technique*

The hierarchical clustering technique using Euclidean distance can be subdivided into agglomerative and divisive methods. The agglomerative methods proceed by a series of successive fusions of the n individuals into groups, while the divisive methods separate the n individuals successively into finer groupings (Everitt, 1993).

Data from this study were analysed using the agglomerative methods. The result of the agglomerative methods was expected to produce a series of partitions of the data, P_n, P_{n-1}, ..., P_1. The first P_n, usually consists of n single-member 'clusters' while the last P_n consist of a single group containing all n individuals. The individuals which are closest to each other are fused together at each specific stage of operation. The results are represented by a two-dimensional diagram. This two-dimensional diagram is referred to as a dendrogram which illustrates the fusions or divisions made at each stages of analysis (Everitt, 1993).

For data analysis, only 13 characters were chosen, and the cluster analysis was run in SPSS version 18. Those characters were: pre-anal pores (PrePores), femoral pores (FemPores), number of supralabials on the right and left (SL), number of infralabials (IL), midbody tubercles rows (MBTR), midventral scales (MVSR), SUBC (subcaudals-scales under the tail), length of the fourth toe (Toe4L), lamellae under fourth toe (Toe4Lam), TTLTW (ratio of total tail length to tail width), TTLTD (ratio of total tail length to tail depth), HWHL (ration of head width to head length), HWHD (ration of head width to head depth) and SUBC (subcaudals- scales under the tail).

These 13 characters were selected based on previous studies where the characters were favourable in identifying and classifying species of the genus *Cyrtodactylus*.

3.2.2.2 *Discriminant Function Analysis (DFA)*

The discriminant function analysis was run using the software, SPSS, version 18. As mentioned earlier, DFA separates two or more groups of individuals into particular groups based on measurements given on number of variables (Manly, 1986). The data for a DFA do not have to be consistent to have zero means and unit variances because its result is not influenced in any significant way by the scaling of individual variables.

At some stage of the computational analysis of the DFA, the stepwise method was used to determine the character that is best to discriminate between individual species. In this method, variables are added one by one to the discriminant functions until the addition of any extra variable do not result in a significantly better discrimination and classification. The DFA produces three significant results, namely, Eigenvalues, Wilks' lambda and standardized canonical discriminant function coefficients, depending on the sample size (Manly, 1986).