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Research Article

Morphometric Analysis of Sumatran, Kalimantan, and Javan *Cyrtodactylus*, which were Labelled as *Cyrtodactylus marmoratus*, Revealed Undescribed Species

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ABSTRACT
Cyrtodactylus marmoratus is originally described based on the specimen from Java. Due to the marbled body colour pattern and the similarity in morphology, many specimens from outside of Java have been identified as *C. marmoratus*. The ongoing research, both molecular and morphological studies, showed that *C. marmoratus* is restricted to Java. The taxonomic status of specimens labelled as *C. marmoratus* from outside Java remains unresolved. Here, we study the morphometric and meristic of Javan, Sumatran, and Kalimantan *Cyrtodactylus* which were labelled as *C. marmoratus* to reveal their taxonomic status. We examined 11 morphometric and 19 meristic characters in 51 specimens at Museum Zoologicum Bogoriense (MZB) originally from, Java, Sumatra, and Kalimantan labelled as *C. marmoratus* as well as other recognized species. Principal Component Analysis (PCA) results show that *C. marmoratus* from Java differs from previous specimens which labelled as *C. marmoratus* from Sumatra and Kalimantan. The PCA results also show that *C. marmoratus* from Martabe differs from *C. marmoratus* Java which is supported by statistical analysis on interorbital, HeadW, HeadD, tubercle on the ventrolateral fold, dorsal tubercle and ventral scales. We hypothesized that *Cyrtodactylus* from Martabe is a suspected undescribed species-await formal description, and overall molecular analyses are needed for future study.

INTRODUCTION
The genus *Cyrtodactylus* (Gray 1827) is the most diverse genera among gekkonids with 305 validated species (Uetz et al. 2021), and it is widely distributed in India, Indochina, Sundaland, Wallacea and Papua (Wood et al. 2012; Grismer et al. 2020). Despite the diversity of *Cyrtodactylus* is relatively high, several species are difficult to recognize because of their morphological similarity to other known species (Davis et al. 2021). The diversity of *Cyrtodactylus* in Sumatra, Java and Borneo islands is still underestimated and much remains undescribed species (O'connell et al. 2019; Davis et al. 2021). Currently, Sumatra consists of seven recognized species (*C. agamensis, C. lateralis,*

C. quadrivirgatus, C. semicinctus, C. psarops, C. consobrinus and *C. marmoratus* (Harvey et al. 2015), whereas Borneo consists of 14 species (*C. consobrinus, C. malayanus, C. baluensis, C. pubisulcus, C. cavernicolus, C. ingeri, C. matsuii, C. hantu, C. limajalur, C. miriensis, C. muluensis, C. quadrivirgatus, C. philippinicus* and *C. yoshii*) (Hikida 1990; Davis et al. 2019; Uetz et al. 2021) and Java consists of three species (*C. marmoratus*, *C. semiadii, C. petani*) (Uetz et al. 2021; Riyanto et al. 2020).

The Java island has a diversity of *Cyrtodactylus* that need further research to reveal hidden species. O'Connel et al (2019) provide the phylogenetics tree of *Cyrtodactylus* on Sumatra and West Java, which West Java has one putative new species in *C. marmoratus* group. However, the dispersal pattern of *C. marmoratus* group in West Java remained unresolved. In this case, *C. marmoratus* is a widely distributed species that can be found in Sumatra, Java, Borneo, Malay Peninsula, and West Papua. Meanwhile, Dring (1979) transferred all specimens of *C. marmoratus* from the Malay Peninsula and Singapore to *C. quadrivirgatus*. The type locality of *C. marmoratus* was mentioned from Java. Mecke et al. (2016b) were done redescription the type series of *C. marmoratus*, which is then based on the compatibilities of morphological characters. Subsequently, Riyanto et al. (2020) determined the specimens from Cibodas as the "true *marmoratus*. Both of Mecke et al (2016b) and Riyanto et al (2022) agree that *C. marmoratus* is restricted to Java.

The taxonomic status of *C. marmoratus* outside Java is remain unresolved. Mecke et al. (2016a) redescription of *C. marmoratus* from Sulawesi resulted that the Sulawesi population belong to *C. fumosus*. These results indicated that the specimens were identified as *C. marmoratus* from Sumatra and Borneo suspected to be different species. In this paper, we examined museum specimens which were labelled as *C. marmoratus* to the revealed taxonomic status of *C. marmoratus* in Sumatra and Kalimantan.

MATERIALS AND METHODS

Materials

We follow Riyanto et al. (2020) to identify specimens from Cibodas (West Java) as the true *C. marmoratus* due to the similarity in its morphology to the recent type series description by Mecke et al. (2016b). A total of 51 specimens collected from Kalimantan and Sumatra which have labelled and have similar pattern to *C. marmoratus* were examined. We included *C. consobrinus, C. malayanus,* and *C. lateralis* as the comparisons. All specimens examined here are stored in Museum Zoologicum Bogoriense (MZB) (Table 1), localities information presented in Figure 1. We applied a methylene blue in 70% ethanol to stain the skin of specimens to get clear visualization of some minute structures, such as sub-digital scales and pores following Harvey et al. (2015).

Methods

Morphological data

Measurements were taken with Mitutoyo® dial callipers to the nearest 0.1

Table 1. Locations, sample-sizes and grouping into primary Operational Taxonomic Units (OTUs).

Localities	Sample size	Species ID	Primary OTU
Bukit Lawang, Sumatra	2	*C. consobrinus*	*C. consobrinus*
Mt. Bondang Murung, Central Kalimantan	1	*C. consobrinus*	*C. consobrinus*
Mt. Meratus, East Kalimantan	2	*C. consobrinus*	*C. consobrinus*
Seulawah Agam, Aceh	6	*C. lateralis*	*C. lateralis*
Ketambe, Aceh, Sumatra	1	*C. lateralis*	*C. lateralis*
Bukit Lawang, Sumatra	1	*C. lateralis*	*C. lateralis*
Bentung Kerihun, West Kalimantan	1	*C. malayanus*	*C. malayanus*
Maruwai, Central Kalimantan	3	*C. malayanus*	*C. malayanus*
Meratus, Central Kalimantan	2	*C. malayanus*	*C. malayanus*
Kutai, East Kalimantan	2	*C. malayanus*	*C. malayanus*
Kerinci National Park, Jambi, Sumatra	3	*C. marmoratus*	*C. marmoratus* (Kerinci)
Cibodas, Bogor, West Java	11	*C. marmoratus*	*C. marmoratus* (Java)
Nunukan, East Kalimantan	3	*C. marmoratus*	*C.marmoratus* (Nunukan)
Martabe, Sumatra	8	*C. marmoratus*	*C.marmoratus* (Martabe)
Kubu Perahu, Lampung, Sumatra	2	*C. marmoratus*	*C.marmoratus* (Lampung)
Mandau, Siak, Riau, Sumatra	3	*C. marmoratus*	*C.marmoratus* (Riau)
Kutai Kartanegara, East Kalimantan	1	*C. marmoratus*	*C.marmoratus* (Kutai)
Sebangau, Palangkaraya, Central Kalimantam	1	*C. marmoratus*	*C.marmoratus* (Kutai)

mm, we followed Grismer et al. (2012) by measuring 11 external body characters: snout-vent length (SVL), measured from the tip of snout to the cloaca opening; tail length (TailL), measured from the cloaca opening to the tip of the original tail; axilla to groin length (AGL), measured from the arm to groin, specimen in supine position; head length (HeadL), measured from the posterior margin of the retroarticular process of the lower jaw to the snout; head width (HeadW), maximum wide measured the angle of the jaws; head

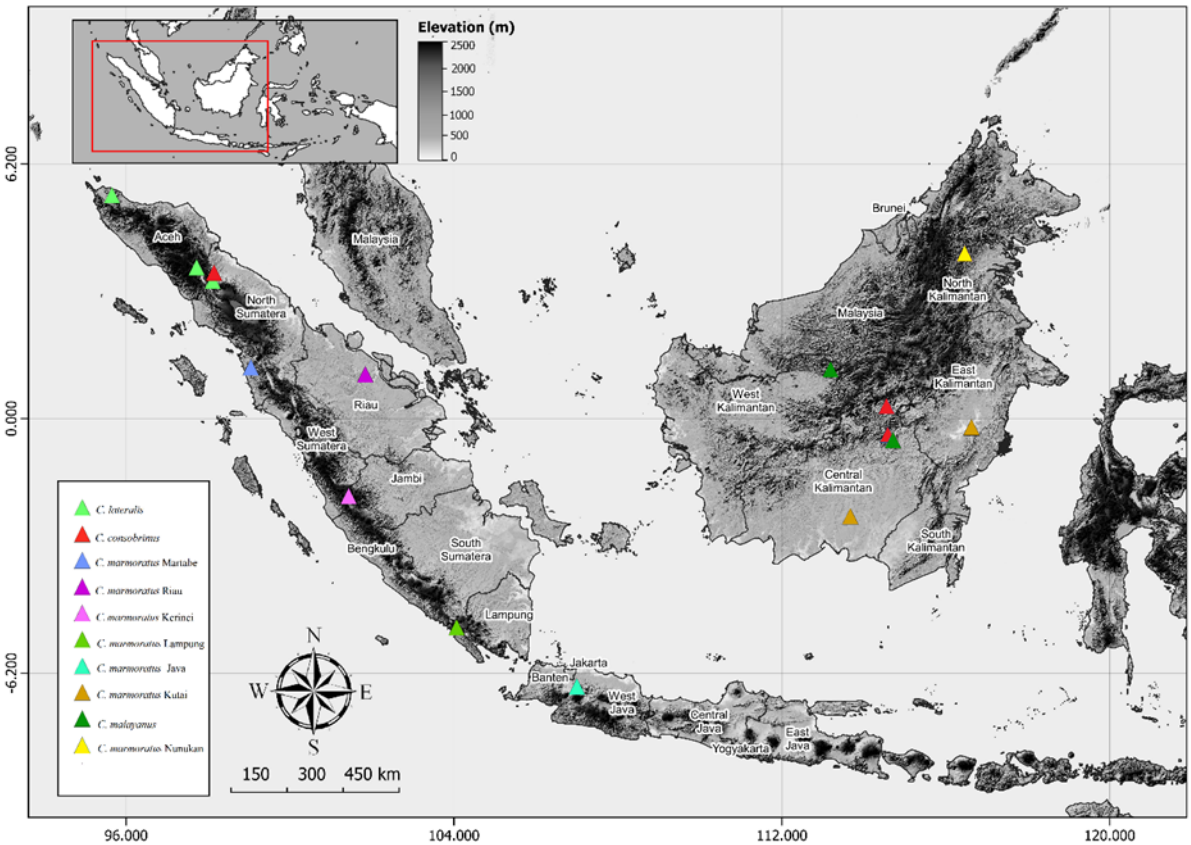

Figure 1. Distribution on the Sunda land (Sumatra, Java, and Kalimantan) of the 10 OTUs specimens used in this study. Map modified by QGIS 3.16 Hannover following this website: https://www.qgis.org/en/site/forusers/download.html.

depth (HeadD), the maximum height of head measured from the top-to-bottom side; eye diameter (EyeD), the greatest horizontal diameter of the eyeball; eye to ear distance (EyeEar), measured from the anterior edge of the ear opening to the posterior edge of the eyeball; eye to snout distance (EyeS), measured from anterior margin of the eye ball to the snout; eye to nostril distance (SnEye), measured between the anterior margin of the eyeball to the posterior margin of the nares; interorbital distance (InteroD), measured between the anterior edges of the orbit; ear length (EarL), the greatest length of the ear opening; and internarial distance (IN), measured between the nares.

We counted the number of supralabials (SuL), number of infralabials (InL), number of dorsal tubercles (DT), number of paravertebral tubercles (PVT), number of ventral scales between lateral body folds at midbody (VS), number of pores at femoral (FP), number of pores at precloacal (PP), number of precloacal and femoral pores which continuous arranged (PFP), and number of subdigital lamellae under 4th toe were counted following Bauer et al. (2010) under a stereoscope (AmScope, magnification 10x to 60x). All measurements and counts were taken on the right side. The illustration for measurement and counted meristic characters is presented in Figure 2. We followed Riyanto et al. (2020) for checked the presence of tubercle on upper (TubBrachium) and lower arms (TubAntebrachium), presence of tubercle on ventrolateral fold, presence of enlarged post cloacal scales and number of tubercle post cloaca. We followed Mecke et al. (2016b) and checked the presence of enlarged femoral scales (EFS), enlarged precloacal scales (EPS), enlarged median subcaudal (SubC) and the condition of precloacal depressions. A groove is always longitudinal and relatively narrow, with some or all of the precloacal scales (usually pore-bearing) on the left and right sides in contact with each other or narrowly separated. The groove may have an entire length slit shape, or a "ʌ" shape with the depression broadening posteriorly. Meanwhile, pit is a triangular depression, with most or all the posterior enlarged precloacal scale series widely separated from each other.

Data analysis

Specimens were divided into a priori Operational Taxonomic Units (OTUs) as a representing putative species due to the upon locations and obvious differences in morphology, and localities. As the consequence, all specimens labelled as *C. marmoratus* both from Kalimantan and Sumatra were relabelled to primary OTUs with added to their respective localities (Table 1).

All morphometric characters before their inclusion in the statistical analyses were adjusted by divided to SVL. We follow Zar (2010) for the small sample size, in performing separate Kruskal-Wallis one-way analysis of variance tests for each of nine morphometric ratios and 15 meristic characters to detect statistical differences between OTUs. The characters which have significant statistical differences will be performed to Dunn test. We performed statistical analysis only specimens which were labelled as *C. marmoratus*. Homogeneity of the priori-OTUs examined by Principal Com-

ponent Analysis (PCA) followed by ordination of specimens along their first two Principal Components (PCs) and the resulting pattern was inspected visually. A biplot of the principal component scores were used to examine the morphometric differentiation between OTU. All statistical analyses were performed in R. (version 4.1.2) (R Core Team 2021).

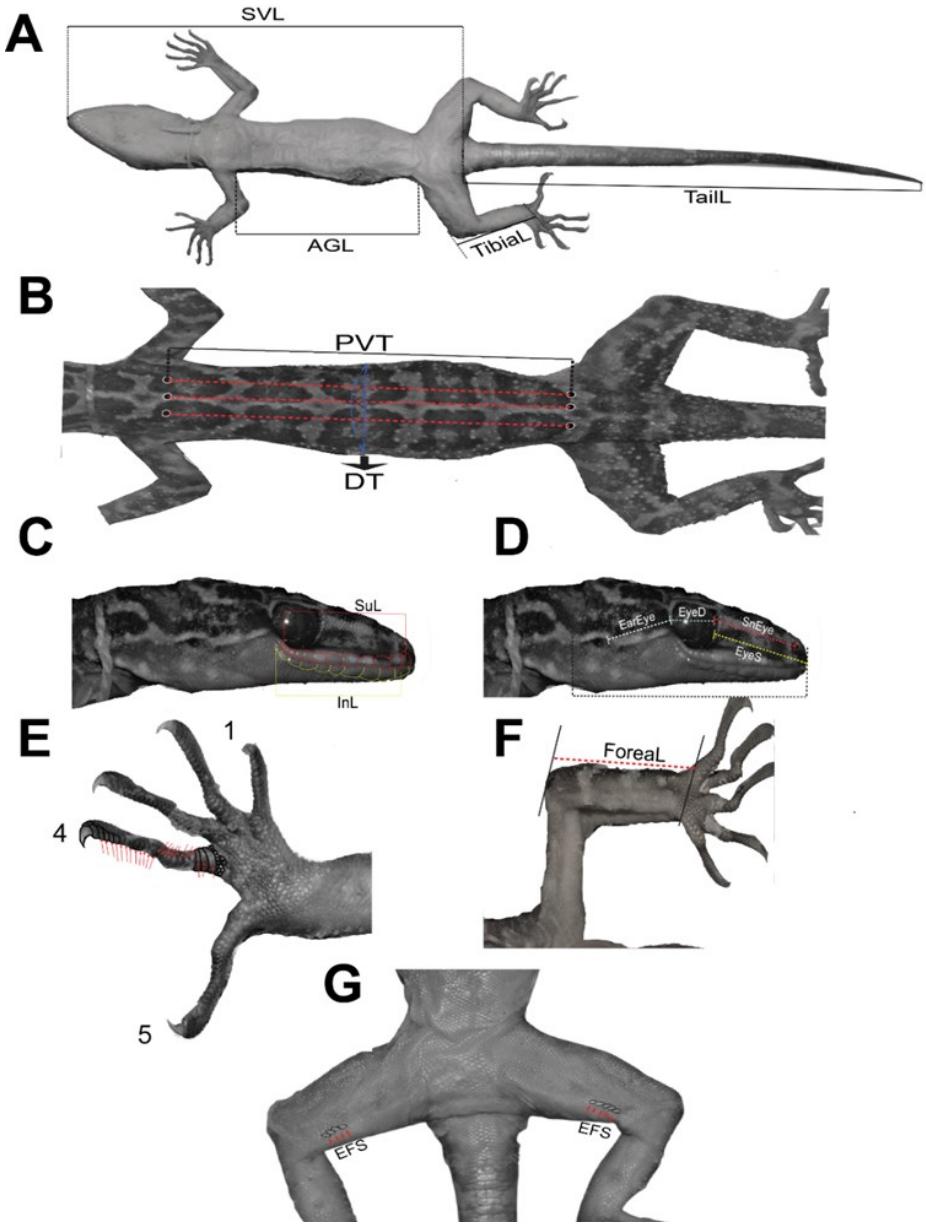

Figure 2. Illustration of measured characters in *Cyrtodactylus*. **A**. Ventral view of the body, **B.** Dorsal view of the body, **C & D.** Lateral view of the head, **E.** View of the subdigitall lamellae under 4th toe, **F.** Ventral view of the forelimb, **G.** View of enlarged femoral scales.

RESULTS AND DISCUSSION

Results

Principal component analysis showed that five components reach 58,5 % for explaining the variation and the total eigenvalue reach 14.0438 (Table 2). In the first PC, morphometric characters have the highest positive correlation including HeadW, HeadD, SnEye, EyeS, and IO, meanwhile, in meristic characters only VS has the highest positive correlation. In contrast, spines

Table 2. Summary analysis of principal component analysis score of Sumatran, Kalimantan and Javan *Cyrtodactylus*

Character	PC1	PC2	PC3	PC4	PC5
AGL/SVL	0.156979329	-0.1047731520	-0.017577464	0.161303205	-0.07102509
HeadL/SVL	0.247976590	0.1548045588	0.152607599	0.154439302	-0.12785407
HeadW/SVL	0.387401006	-0.0007062378	-0.152955681	-0.093274456	0.01332827
HeadD/SVL	0.321194914	-0.1247859036	-0.146126871	0.042263714	-0.03890982
EyeS/SVL	0.339506083	0.0374904712	0.113425315	0.013576318	-0.11152219
EyeD/SVL	-0.048223921	0.2631359450	0.039981276	0.325266169	0.24191758
SnEye/SVL	0.328166997	0.1025988828	0.117406218	-0.006155799	0.10230859
EarEye/SVL	0.159169926	0.1081510718	0.047441474	0.020439091	-0.08187862
IO/SVL	0.257882384	-0.0991033079	-0.401818209	0.153104059	0.19897514
TubLA	-0.005029344	-0.1951094491	0.386515065	-0.119819618	0.38423815
SubCa	0.105099365	-0.4090890411	0.211396239	-0.131384872	-0.15510277
Spines	-0.304670099	-0.0819113423	-0.299208775	0.255526172	0.05072730
SuL	-0.124357557	0.3223170942	0.163640764	-0.241888743	0.13300855
InL	0.075308957	0.0722428672	-0.037937543	-0.293111049	0.33601431
TubBrachium	-0.138683850	0.2024149568	-0.143979780	0.049260554	-0.23023212
TubAntebrachium	0.040920158	0.2024149568	-0.134921092	-0.232552812	-0.03316241
PVT	-0.184273135	-0.1186416582	0.091083435	0.359726487	-0.30461448
DT	-0.251274883	-0.0516968099	0.120578545	-0.289238110	-0.05011188
VS	0.281242210	0.1980686805	0.006832648	-0.194381401	-0.22696191
Toe4th	-0.030271656	0.2419296242	-0.278781743	-0.155091016	-0.05536596
EFS	0.014774424	-0.3248167963	0.039410353	-0.195999762	-0.32730647
EPS	0.130307246	0.0208115941	0.127516061	0.370515709	0.31658363
Enlarge Post Cloaca Scale	0.002137374	0.2472410278	0.501559727	0.094961333	-0.03050341
Tubercle Post Cloaca	0.056978099	0.1950744514	0.137696274	0.228704799	-0.36339726
Standard deviation	2.1260	1.8790	1.5649	1.41876	1.23757
Proportion of variance	0.1883	0.1471	0.1020	0.08387	0.06382
Cumulative proportion	0.1883	0.3354	0.4375	0.52134	0.58516
Eigenvalue	4.51973073	3.53071478	2.44891599	2.01287319	1.53156920

and DT have the highest negative correlation. In the second PC, EyeD, SuL, and Toe4th showed the highest positive correlation on the morphometric and meristic characters whereas SubCa and EFS showed the highest negative correlation. The highest positive correlation on the third PC are enlarged post cloaca scales and TubLa while IO and spines showed the highest negative correlation. In the fourth and fifth PC, EyeD and EPS showed similar value of positive correlation, while EPS character has the highest positive correlation in the fourth PC and TubLa in the fifth PC, respectively.

Principal component analysis based on the nine morphometric characters and 15 meristic characters (PC1–PC2, PC1–PC3, and PC2–PC3 (Figure 3) showed that there are five distinct OTUs, i.e. *C. malayanus, C. consobrinus, C. lateralis, C. marmoratus* from Martabe and *C. marmoratus* from Java. It clear that *C. marmoratus* (specimens originally from Cibodas, West Java) is differs from specimens previously labelled as *"marmoratus"* that originally from Martabe. We hypothesized that *C. marmoratus* frrom Martabe is suspected undescribed species. It is considered by statistical difference on interobital, HeadW, HeadD, tubercle on ventrolateral fold, dorsal tubercle and ventral scales. The comparison of morphometric and meristic among *C. marmoratus* group are presented in table 3 and 4.

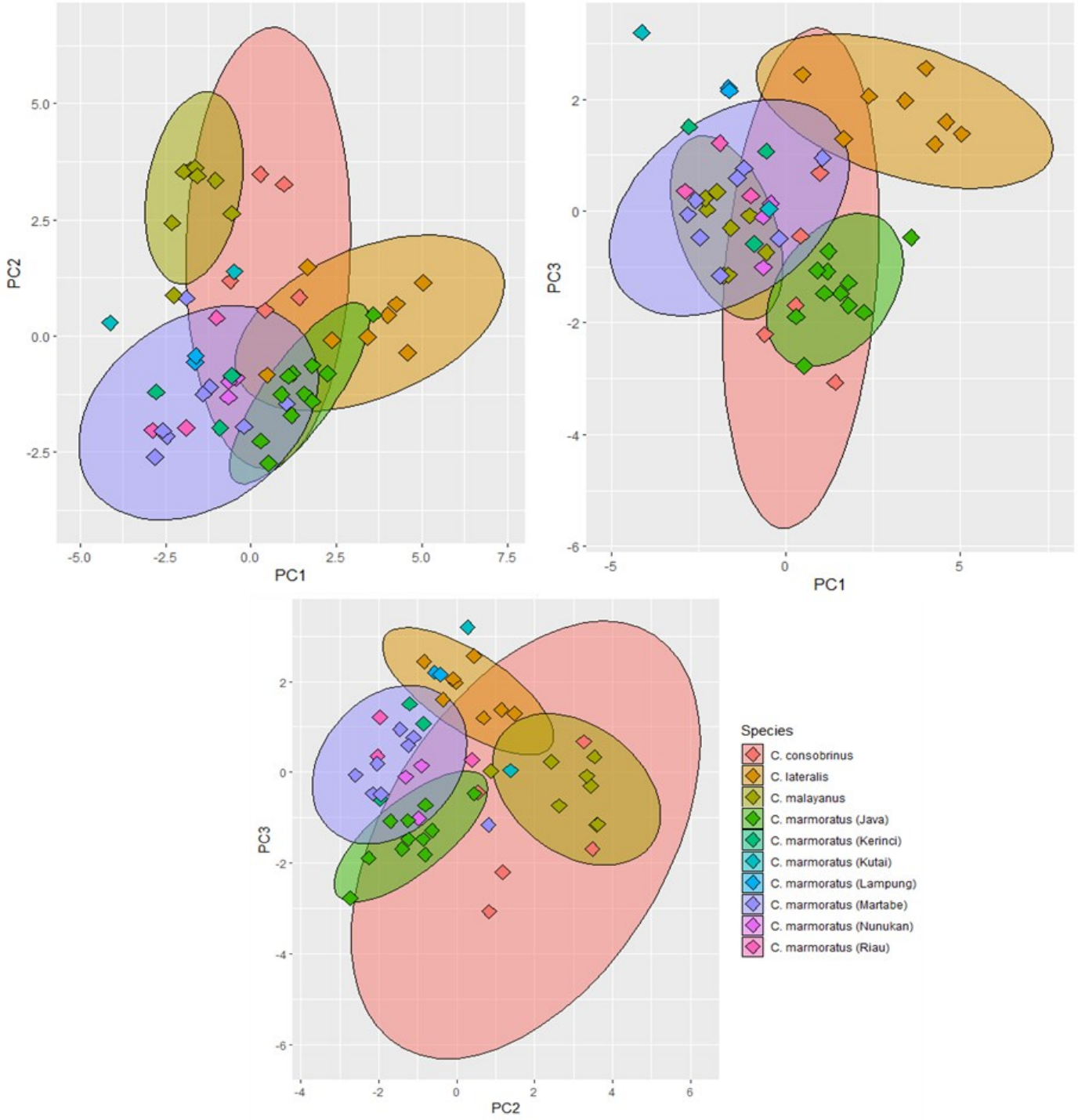

Figure 3. Principal component analysis biplot of morphometric variation in primary OTUs, each point represents an individual specimen.

Referring to the biplots on three PC (Figure 3), show that the *C. marmoratus* from Java is clearly different from other specimens which labelled as *C. marmoratus* as well as other recognized species. It means similarity on dorsal color pattern is not supported as a diagnostic character to distinguish *C. marmoratus*. *Cyrtodactylus marmoratus* is easily distinguished from the other OTUs in this study by the following combination of characters such as the absence of tubercles on the upper arms, subcaudal not enlarged, presence of enlarged precloacofemoral, vary in arrangement of precloacal and femoral pores vary continuous and not, and presence of groove precloacal depression in male (Table 5).

Table 3. Summary statistics of Kruskal-Wallis and Dunn test of the morphometric characters on the specimens which were labelled as *C. marmoratus*.

Head Length	**Z**	**P.adj**	**Head Depth**	**Z**	**P.adj**
Java – Kerinci	2.01355599	0.2312949	Java – Kerinci	2.35080182	0.098348294
Java - Kutai	0.85096053	0.7536924	Java - Kutai	2.61591570	0.093437952
Java – Lampung	1.68301082	0.2771190	Java – Lampung	1.99187798	0.162345567
Java – Martabe	-0.34151660	0.9051182	Java – Martabe	3.49598294	0.009918697
Java – Riau	2.24023648	0.2020011	Java – Riau	2.35080182	0.131131058
Java – Nunukan	1.52256573	0.3356519	Java – Nunukan	2.24169287	0.104921161
Kerinci – Kutai	-0.72011152	0.8250486	Kerinci – Kutai	0.52548679	1.000000000
Kerinci – Lampung	-0.01946247	0.9844722	Kerinci – Lampung	0.00000000	1.000000000
Kerinci – Martabe	-2.17162431	0.2091881	Kerinci – Martabe	0.13777677	1.000000000
Kerinci – Riau	0.26111648	0.8775819	Kerinci – Riau	0.00000000	1.000000000
Kerinci – Nunukan	-0.39167473	0.9734180	Kerinci – Nunukan	-0.08703883	1.000000000
Kutai – Lampung	0.63960215	0.7836469	Kutai – Lampung	-0.47970161	1.000000000
Kutai – Martabe	-1.02815479	0.7090464	Kutai – Martabe	-0.48879490	1.000000000
Kutai – Riau	0.95366121	0.7145358	Kutai – Riau	-0.52548679	1.000000000
Kutai – Nunukan	0.36978700	0.9338978	Kutai – Nunukan	-0.60333668	1.000000000
Lampung – Martabe	-1.83719463	0.2779609	Lampung – Martabe	0.11798498	1.000000000
Lampung – Riau	0.25301216	0.8716474	Lampung – Riau	0.00000000	1.000000000
Lampung - Nunukan	-0.33086205	0.8642068	Lampung - Nunukan	-0.07784989	1.000000000
Martabe - Riau	2.39975617	0.2460899	Martabe - Riau	-0.13777677	1.000000000
Martabe – Nunukan	1.69924682	0.3124544	Martabe – Nunukan	-0.24274955	1.000000000
Nunukan – Riau	0.65279121	0.8301314	Nunukan – Riau	0.08703883	1.000000000
Head Width	**Z**	**P.adj**	**Eye Diameter**	**Z**	**P.adj**
Java – Kerinci	1.7955026	0.254007779	Java – Kerinci	1.4481733	0.23838004
Java - Kutai	2.1685722	0.210806224	Java - Kutai	1.8973268	0.13483124
Java – Lampung	1.8218528	0.287604735	Java – Lampung	-1.9162370	0.14525419
Java – Martabe	4.0894495	0.000908036	Java – Martabe	-1.4208134	0.23305654
Java – Riau	3.0503705	0.023998717	Java – Riau	0.6298562	0.61692013
Java – Nunukan	1.9319013	0.280201349	Java – Nunukan	-1.6614317	0.18446931
Kerinci – Kutai	0.5449992	0.946218101	Kerinci – Kutai	0.5644117	0.60109765
Kerinci – Lampung	0.2530353	0.933614382	Kerinci – Lampung	-2.6468964	0.04264797
Kerinci – Martabe	1.0793503	0.841294828	Kerinci – Martabe	-2.3684483	0.06252007
Kerinci – Riau	1.0010383	0.831621814	Kerinci – Riau	-0.6527912	0.63480640
Kerinci – Nunukan	0.1088085	0.913354376	Kerinci – Nunukan	-2.4806066	0.05508680
Kutai – Lampung	-0.2665253	0.975678110	Kutai – Lampung	-2.9315098	0.07083692
Kutai – Martabe	0.2949895	1.000000000	Kutai – Martabe	-2.6799445	0.05154406
Kutai – Riau	0.3503566	1.000000000	Kutai – Riau	-1.1482859	0.35119076
Kutai – Nunukan	-0.4476779	0.981578488	Kutai – Nunukan	-2.7831337	0.05652844
Lampung – Martabe	0.6321203	0.922789472	Lampung – Martabe	1.0281548	0.39883859
Lampung – Riau	0.6423205	0.993997027	Lampung – Riau	2.0630222	0.11733156
Lampung - Nunukan	-0.1557141	0.968496142	Lampung - Nunukan	0.4281744	0.66852414
Martabe - Riau	0.1279473	0.943100215	Martabe - Riau	1.5811524	0.19922558
Martabe – Nunukan	-0.9481223	0.800490153	Martabe – Nunukan	-0.6232759	0.58921939
Nunukan – Riau	0.8922298	0.781766571	Nunukan – Riau	1.8278154	0.14191225

Table 3. Contd.

Interorbital	Z	P.adj
Java – Kerinci	1.66143166	0.4058324877
Java - Kutai	2.40159971	0.0856986879
Java – Lampung	1.22286180	0.5811274881
Java – Martabe	4.17380216	0.0006290716
Java – Riau	2.75252112	0.0413968328
Java – Nunukan	2.80707559	0.0524931847
Kerinci – Kutai	0.83688636	0.6039846680
Kerinci – Lampung	-0.15569979	1.0000000000
Kerinci – Martabe	1.26623411	0.7190024721
Kerinci – Riau	0.87038828	0.6204502492
Kerinci – Nunukan	0.91390769	0.6887338511
Kutai – Lampung	-0.90610304	0.6385422996
Kutai – Martabe	0.11798498	1.0000000000
Kutai – Riau	-0.05838742	1.0000000000
Kutai – Nunukan	-0.01946247	0.9844721731
Lampung – Martabe	1.26412474	0.6185557719
Lampung – Riau	0.93419873	0.7354229173
Lampung - Nunukan	0.97312368	0.7711476177
Martabe - Riau	-0.21650635	1.0000000000
Martabe – Nunukan	-0.16401996	1.0000000000
Nunukan – Riau	-0.04351941	1.0000000000

Table 4. Summary statistics of Kruskal-Wallis and Dunn test of the meristic characters of specimens which were labelled as *C. marmoratus*.

Tubercle on Ventrolateral Fold	Z	P.adj
Java – Kerinci	-2.7692096	0.03933473
Java - Kutai	0.2346403	0.95023595
Java – Lampung	-2.3464027	0.09951698
Java – Martabe	-3.3480083	0.01709286
Java – Riau	-1.7538328	0.18540472
Java – Nunukan	-2.7692096	0.05900209
Kerinci – Kutai	2.1734327	0.08924331
Kerinci – Lampung	0.0000000	1.00000000
Kerinci – Martabe	-3.3480083	0.93727903
Kerinci – Riau	0.8099905	0.73140483
Kerinci – Nunukan	0.0000000	1.00000000
Kutai – Lampung	-1.9840635	0.12402800
Kutai – Martabe	-2.1959559	0.11799943
Kutai – Riau	-1.4489551	0.30943525
Kutai – Nunukan	-2.1734327	0.10411719
Lampung – Martabe	0.3137080	0.93109409
Lampung – Riau	0.7244776	0.75724805
Lampung - Nunukan	0.0000000	1.00000000
Martabe – Riau	0.6105533	0.81224299
Martabe – Nunukan	-0.3663320	0.99976430
Nunukan – Riau	0.8099905	0.79789618

Dorsal Tubercle	Z	P.adj
Java – Kerinci	-1.2612422	0.36263779
Java - Kutai	-1.8120993	0.18367351
Java – Lampung	-3.0666295	0.04546227
Java – Martabe	-2.6231004	0.04574514
Java – Riau	-2.6321577	0.05939114
Java – Nunukan	0.4386929	0.73045078
Kerinci – Kutai	-0.6260202	0.65631389
Kerinci – Lampung	-1.6824292	0.21579985
Kerinci – Martabe	-0.5869309	0.65012510
Kerinci – Riau	-1.0936122	0.44281746
Kerinci – Nunukan	1.3560791	0.33423216
Kutai – Lampung	-0.9643651	0.50229439
Kutai – Martabe	0.2202482	0.82567788
Kutai – Riau	-0.3521363	0.76097282
Kutai – Nunukan	1.8389342	0.19777459
Lampung – Martabe	1.4400842	0.31467150
Lampung – Riau	0.7042727	0.63165766
Lampung - Nunukan	2.8953432	0.03976814
Martabe - Riau	-0.7320150	0.64982318
Martabe – Nunukan	2.2224239	0.09189135
Nunukan – Riau	-2.4496913	0.06005106

Table 4. Contd.

Paravertebral Tubercles	Z	P.adj
Java – Kerinci	-0.1546255	0.87711658
Java – Kutai	1.1474557	0.43958832
Java – Lampung	1.8448045	0.22773095
Java – Martabe	-2.7163266	0.04620753
Java – Riau	-1.1971005	0.44151043
Java – Nunukan	1.0524509	0.43888909
Kerinci – Kutai	1.0765704	0.45500899
Kerinci – Lampung	1.6637906	0.20192399
Kerinci – Martabe	-1.7155831	0.20122287
Kerinci – Riau	-0.8316074	0.53239014
Kerinci – Nunukan	0.9629138	0.46982707
Kutai – Lampung	0.5360563	0.65422700
Kutai – Martabe	-2.7122540	0.03508436
Kutai – Riau	-1.8203827	0.20610224
Kutai – Nunukan	-0.2153141	0.87099858
Lampung – Martabe	-3.3903175	0.01466046
Lampung – Riau	-2.4076029	0.06744207
Lampung - Nunukan	-0.8025343	0.52159547
Martabe - Riau	0.7126268	0.55542283
Martabe – Nunukan	2.8769009	0.04216818
Nunukan – Riau	-1.7945212	0.19091628

Ventral Scales	Z	P.adj
Java – Kerinci	1.7871873	0.17245017
Java - Kutai	-1.3160638	0.35920050
Java – Lampung	2.6511092	0.04211964
Java – Martabe	2.9177854	0.02467688
Java – Riau	0.1991295	0.84216144
Java – Nunukan	1.1300600	0.38767645
Kerinci – Kutai	-2.3833939	0.07204609
Kerinci – Lampung	0.9572648	0.47380710
Kerinci – Martabe	0.2831803	0.81589052
Kerinci – Riau	-1.2668319	0.35912696
Kerinci – Nunukan	-0.5242063	0.66330717
Kutai – Lampung	3.0495901	0.04812231
Kutai – Martabe	2.9946073	0.02885383
Kutai – Riau	1.2503050	0.34115010
Kutai – Nunukan	1.9145295	0.16665760
Lampung – Martabe	-0.8628530	0.47956380
Lampung – Riau	-2.0903536	0.12805116
Lampung - Nunukan	-1.4261291	0.32304526
Martabe - Riau	-1.8110371	0.18410467
Martabe – Nunukan	-0.9153969	0.47247807
Nunukan – Riau	-0.7426256	0.53399312

Supralabial	Z	P.adj
Java – Kerinci	-1.83487298	0.23283579
Java - Kutai	-2.29250012	0.15313761
Java – Lampung	-3.12703613	0.03708143
Java – Martabe	-2.03680405	0.21876583
Java – Riau	-2.46293416	0.14469548
Java – Nunukan	-1.34955297	0.46504348
Kerinci – Kutai	-0.62126485	0.70143330
Kerinci – Lampung	-1.32400707	0.43283496
Kerinci – Martabe	0.36735791	0.78844176
Kerinci – Riau	0.50101951	0.76138267
Kerinci – Nunukan	0.38715144	0.81508478
Kutai – Lampung	-0.64151294	0.72966527
Kutai – Martabe	1.03196138	0.63438944
Kutai – Riau	0.17313939	0.90566896
Kutai – Nunukan	0.96754363	0.58322660
Lampung – Martabe	1.84341819	0.27412550
Lampung – Riau	0.87588160	0.57164161
Lampung - Nunukan	1.67028584	0.28458847
Martabe – Riau	-0.97161017	0.63237591
Martabe – Nunukan	0.09956429	0.92069024
Nunukan – Riau	-0.88817094	0.60487884

Enlarged Femoral Scales	Z	P.adj
Java – Kerinci	0.000000	1.0000000000
Java - Kutai	1.935782	0.1851303342
Java – Lampung	0.000000	1.0000000000
Java – Martabe	0.000000	1.0000000000
Java – Riau	0.000000	1.0000000000
Java – Nunukan	4.569196	0.0001028158
Kerinci – Kutai	1.630074	0.2164800825
Kerinci – Lampung	0.000000	1.0000000000
Kerinci – Martabe	0.000000	1.0000000000
Kerinci – Riau	0.000000	1.0000000000
Kerinci – Nunukan	3.644957	0.0014040396
Kutai – Lampung	-1.488048	0.2610459144
Kutai – Martabe	-1.882248	0.1794070958
Kutai – Riau	-1.630074	0.2706001031
Kutai – Nunukan	1.630074	0.2405334250
Lampung – Martabe	0.000000	1.0000000000
Lampung – Riau	0.000000	1.0000000000
Lampung - Nunukan	3.260149	0.0046768555
Martabe - Riau	0.000000	1.0000000000
Martabe – Nunukan	4.395984	0.0001157857
Nunukan – Riau	-3.644957	0.0018720528

Table 4. Contd.

Infralabial	Z	P.adj
Java – Kerinci	-2.3910922	0.11758834
Java – Kutai	-0.8818600	0.61037718
Java – Lampung	-2.3742384	0.09232227
Java – Martabe	0.2539041	0.79956964
Java – Riau	-0.3068924	0.83881214
Java – Nunukan	-1.6278641	0.27182848
Kerinci – Kutai	0.9634662	0.58679881
Kerinci – Lampung	-0.2932289	0.80781459
Kerinci – Martabe	2.4747159	0.28001861
Kerinci – Riau	1.6626162	0.28916783
Kerinci – Nunukan	0.6088454	0.75967770
Kutai – Lampung	-1.1472004	0.58636387
Kutai – Martabe	1.0067051	0.59960059
Kutai – Riau	0.5236230	0.78820982
Kutai – Nunukan	-0.4188984	0.78783882
Lampung – Martabe	2.4578116	0.14677580
Lampung – Riau	1.7803180	0.31510050
Lampung - Nunukan	0.8377967	0.60321732
Martabe - Riau	-0.4695253	0.78897522
Martabe – Nunukan	-1.7404208	0.28624808
Nunukan – Riau	1.0537709	0.61317446

Tubercle post cloaca	Z	P.adj
Java – Kerinci	2.5173879	0.04965601
Java - Kutai	2.1330294	0.11522809
Java – Lampung	0.8295114	0.65716279
Java – Martabe	-0.7841682	0.56823565
Java – Riau	2.5173879	0.06207001
Java – Nunukan	1.4917854	0.35635795
Kerinci – Kutai	0.0000000	1.00000000
Kerinci – Lampung	-1.0976604	0.51994629
Kerinci – Martabe	-2.9601699	0.03228429
Kerinci – Riau	0.0000000	1.00000000
Kerinci – Nunukan	-0.8181477	0.57858197
Kutai – Lampung	-1.0020222	0.55358248
Kutai – Martabe	-2.5349381	0.07872705
Kutai – Riau	0.0000000	1.00000000
Kutai – Nunukan	-0.7317736	0.57355543
Lampung – Martabe	-1.2674690	0.47830447
Lampung – Riau	1.0976604	0.57194092
Lampung - Nunukan	0.3658868	0.83352448
Martabe - Riau	2.9601699	0.06456858
Martabe – Nunukan	1.9734466	0.14533411
Nunukan – Riau	0.8181477	0.61990925

Enlarged median subcaudal	Z	P.adj
Java – Kerinci	0.000000	1.000000000
Java - Kutai	3.679465	0.004908202
Java – Lampung	0.000000	1.000000000
Java – Martabe	0.000000	1.000000000
Java – Riau	0.000000	1.000000000
Java – Nunukan	0.000000	1.000000000
Kerinci – Kutai	3.098387	0.008172250
Kerinci – Lampung	0.000000	1.000000000
Kerinci – Martabe	0.000000	1.000000000
Kerinci – Riau	0.000000	1.000000000
Kerinci – Nunukan	0.000000	1.000000000
Kutai – Lampung	-2.828427	0.016372072
Kutai – Martabe	-3.577709	0.003639503
Kutai – Riau	-3.098387	0.013620416
Kutai – Nunukan	-3.098387	0.010215312
Lampung – Martabe	0.000000	1.000000000
Lampung – Riau	0.000000	1.000000000
Lampung - Nunukan	0.000000	1.000000000
Martabe - Riau	0.000000	1.000000000
Martabe – Nunukan	0.000000	1.000000000
Nunukan – Riau	0.000000	1.000000000

Enlarged post cloacal scales	Z	P.adj
Java – Kerinci	0.000000	1.0000000000
Java - Kutai	0.000000	1.0000000000
Java – Lampung	0.000000	1.0000000000
Java – Martabe	-4.459790	0.0001722842
Java – Riau	0.000000	1.0000000000
Java – Nunukan	-3.181580	0.0153797960
Kerinci – Kutai	0.000000	1.0000000000
Kerinci – Lampung	0.000000	1.0000000000
Kerinci – Martabe	-3.060970	0.0115825990
Kerinci – Riau	0.000000	1.0000000000
Kerinci – Nunukan	-2.538023	0.0292637106
Kutai – Lampung	0.000000	1.0000000000
Kutai – Martabe	-2.621258	0.0306620401
Kutai – Riau	0.000000	1.0000000000
Kutai – Nunukan	-2.270076	0.0487261938
Lampung – Martabe	-2.621258	0.0367944481
Lampung – Riau	0.000000	1.0000000000
Lampung - Nunukan	-2.270076	0.0541402153
Martabe - Riau	3.060970	0.0154434653
Martabe – Nunukan	0.000000	1.0000000000
Nunukan – Riau	2.538023	0.0334442407

Table 5. Morphometric (in mm) and meristic characters of OTUs examined in this study. The number of precloacal pores not given for specimen with precloacal and femoral pores in a continuous series.

Character	OTU									
	C. marmoratus (n=11)	*C. lateralis* (n=8)	*C. malayanus* (n=8)	*C. marmoratus* Nunukan (n=3)	*C. consobrinus* (n=5)	*C. marmoratus* Kerinci (n=3)	*C. marmoratus* Riau (n=3)	*C.marmoratus* Martabe (n=8)	*C. marmoratus* Lampung (n=2)	*C. marmoratus* Kutai (n=2)
SVL	73.7±7.5 (59.6-85.2)	74.7±11.2 (57.6-88.9)	85.9±8.4 (68.6-95.1)	58.1±6.61 (50.5-62.3)	80.1±30.2 (42.5-118.6)	69.4±4.8 (65.2-74.8)	60.9±6.5 (53.6-66.2)	57.4±5.0 (50.5-62.9)	53.6±2.7 (51.7-55.6)	68.7±1.5 (67.6-69.8)
TL/SVL	0.822±0.214 (0.450-1.003)	0.970±0.207 (0.502-1.173)	1.008±0.368 (0.278-1.331)	1.064±0.102 (0.952-1.154)	1.038±0.233 (0.781-1.352)	1.026±0.116 (0.894-1.115)	1.214±0.083 (1.118-1.274)	0.900±0.419 (0.126-1.351)	0.747±0.077 (0.692-0.802)	1.219±0.203 (1.075-1.363)
AGL/SVL	0.473±0.062 (0.385-0.630)	0.457±0.045 (0.402-0.544)	0.428±0.023 (0.383-0.453)	0.449±0.036 (0.407-0.477)	0.413±0.017 (0.390-0.435)	0.427±0.033 (0.406-0.466)	0.433±0.030 (0.401-0.462)	0.423±0.024 (0.377-0.449)	0.423±0.003 (0.421-0.426)	0.396±0.022 (0.380-0.412)
HeadL/SVL	0.277±0.016 (0.260-0.316)	0.288±0.016 (0.273-0.320)	0.278±0.016 (0.266-0.318)	0.261±0.009 (0.251-0.269)	0.273±0.021 (0.238-0.289)	0.259±0.003 (0.255-0.262)	0.254±0.008 (0.248-0.264)	0.279±0.015 (0.263-0.308)	0.256±0.017 (0.244-0.268)	0.264±0.020 (0.250-0.273)
HeadW/SVL	0.187±0.011 (0.170-0.215)	0.191±0.029 (0.151-0.250)	0.162±0.011 (0.139-0.174)	0.163±0.005 (0.157-0.168)	0.174±0.007 (0.166-0.183)	0.166±0.016 (0.150-0.183)	0.151±0.016 (0.132-0.161)	0.156±0.007 (0.148-0.168)	0.161±0.007 (0.156-0.167)	0.160±0.008 (0.153-0.166)
HeadD/SVL	0.119±0.005 (0.110-0.130)	0.112±0.013 (0.094-0.134)	0.096±0.009 (0.081-0.109)	0.104±0.005 (0.100-0.110)	0.112±0.010 (0.103-0.128)	0.100±0.014 (0.086-0.114)	0.102±0.010 (0.091-0.111)	0.102±0.006 (0.094-0.114)	0.105±0.006 (0.100-0.109)	0.098±0.004 (0.094-0.101)
EyeS/SVL	0.118±0.007 (0.107-0.129)	0.123±0.004 (0.116-0.128)	0.111±0.003 (0.106-0.116)	0.107±0.001 (0.105-0.109)	0.112±0.009 (0.096-0.120)	0.107±0.009 (0.099-0.117)	0.112±0.003 (0.108-0.115)	0.113±±0.010 (0.103-0.135)	0.110±0.002 (0.108-0.112)	0.105±0.010 (0.097-0.113)
EyeD/SVL	0.055±0.004 (0.051-0.065)	0.057±0.007 (0.045-0.067)	0.070±0.011 (0.059-0.089)	0.066±0.010 (0.057-0.077)	0.068±0.007 (0.059-0.075)	0.049±0.002 (0.048-0.052)	0.053±0.004 (0.483-0.057)	0.065±0.019 (0.049-0.111)	0.067±0.003 (0.065-0.070)	0.039±0.007 (0.034-0.044)
SnEye/SVL	0.081±0.005 (0.074-0.090)	0.091±0.009 (0.079-0.106)	0.078±0.006 (0.069-0.090)	0.083±0.002 (0.081-0.085)	0.082±0.009 (0.070-0.092)	0.069±0.002 (0.068-0.072)	0.076±0.016 (0.057-0.088)	0.079±0.009 (0.069-0.100)	0.080±0.001 (0.079-0.081)	0.071±0.008 (0.065-0.077)
EarEye/SVL	0.088±0.006 (0.076-0.100)	0.094±0.007 (0.086-0.110)	0.088±0.022 (0.065-0.138)	0.093±0.004 (0.089-0.099)	0.087±0.002 (0.827-0.090)	0.091±0.011 (0.083-0.104)	0.083±0.008 (0.074-0.090)	0.083±0.007 (0.071-0.095)	0.077±0.002 (0.075-0.079)	0.086±0.009 (0.079-0.093)
IO/SVL	0.051±0.003 (0.046-0.056)	0.041±0.008 (0.024-0.050)	0.034±0.001 (0.032-0.037)	(0.033±0.002 (0.030-0.035)	0.054±0.017 (0.036-0.080)	0.041±0.006 (0.036-0.049)	0.034±0.004 (0.029-0.038-)	0.032±0.004 (0.027-0.040)	0.040±0.001 (0.039-0.041)	0.034±0.008 (0.028-0.040)
Suprlabial	8–11	10–12	12–13	10–11	8-12	10–13	11–12	10–12	12–13	11–12
Infralabial	9–11	9–11	9–11	10–11	8–14	10–12	9–10	8–10	11	10
Tubercle on brachium	absent	absent	absent	absent	absent	absent	Absent	absent	absent	absent
Tubercle on antebrachium	present	present	present	absent	present	present	Absent	present	present	present
Tubercle on hindlimbs	present	present	present	present	present	present	present	present	present	present
Tubercle on ventrolateral fold	absent	present	present	present	absent	absent	absent	present	absent	present
DT	14–23	17–22	17–23	16–18	14–20	18–25	22–25	19–24	18–19	20–24
PVT	24–33	22–30	24–32	26–30	26–32	27–33	31–33	31–36	28	27

Table 5. Contd.

Character	OTU									
	C. marmoratus (n=11)	*C. lateralis* (n=8)	*C. malayanus* (n=8)	*C. marmoratus* Nunukan (n=3)	*C. consobrinus* (n=5)	*C. marmoratus* Kerinci (n=3)	*C. marmoratus* Riau (n=3)	*C.marmoratus* Martabe (n=8)	*C. marmoratus* Lampung (n=2)	*C. marmoratus* Kutai (n=2)
VS	39–47	51–60	34–53	35–42	44–48	28–46	40–43	30–40	30	48–49
EPS	present	present	absent	present	present	present	present	present	absent	present
EFS	present	present	absent	absent	present	present	present	present	present	absent
PP	-	7–10	6–10	5–6	8-10	-	-	-	0	7
EPFS	yes	no	no	no	No	yes	yes	yes		no
PFP	45-52	0	0	0	0	35–45	46–49	39–47	0	0
Precloacal depression	groove	groove	pit	pit	pit	pit	pit	Pit	N/A	no
Tubercle post cloacal	1–2	2–3	1–3	1–2	0–3	1	1	2	1–2	0
Enlaraged median sub-caudal	absent	absent	present	absent	present	absent	absent	absent	N/A	present (in male)
Enlarged post cloacal scales	absent	present	present	present	present	absent	absent	present	N/A	absent
Subdigital lamella 4th toe	19–24	21–22	18–26	17–19	23–27	20–24	22–23	19–22	21–23	20–23

Cyrtodactylus marmoratus from Martabe differs from the other OTUs by its unique combination of characters such as the absence of tubercle on the upper arm, presence of tubercles along ventrolateral folds, and presence of EPFS. As the result of our statistical analysis, *C. marmoratus* from Martabe (Sumatra) is differ with *C. marmoratus* from Java. The *C. marmoratus* from Martabe can be distinguished from Java specimens by combination characters: more supralabial (10-12 vs 8-11), presence of tubercle on ventrolateral fold (vs absent), more number of paravertebral tubercle (31-36 vs 24-33), precloacal depression in groove form (vs pit), and presence of enlarged post cloacal scales (vs absent) (Figure 4).

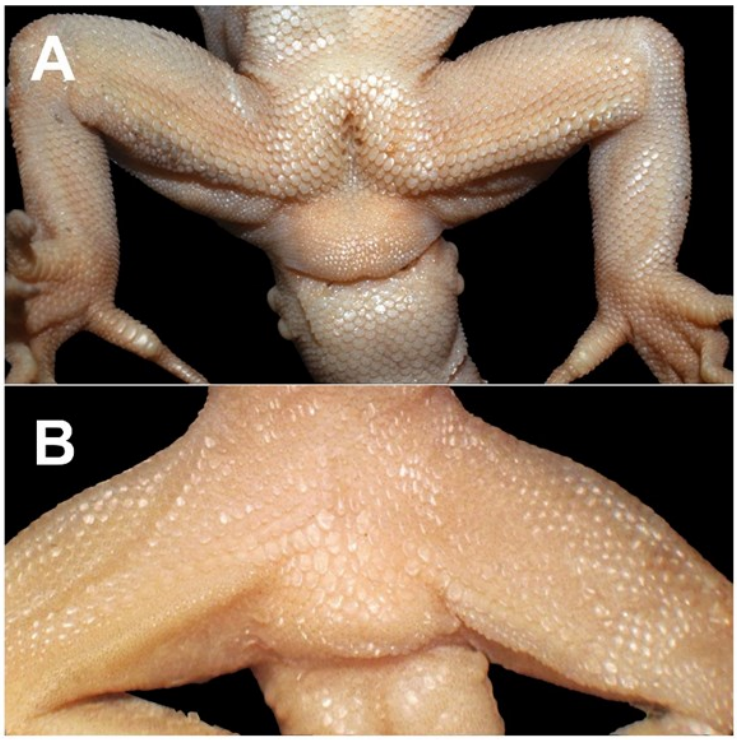

Figure 4. Comparison of precloacal region. **A** *C. marmoratus* from Java, **B** *C. marmoratus* from Martabe

Discussion

We assigned that specimens *C. marmortaus* from Kerinci belong to *C. semicinctus* described by Harvey et al. (2015). It is based on similarity in its morphology including fewer supralabial (10-13 vs 10-15), presence of tubercles on antebrachium, absence of tubercle on brachium, matching the number of paravertebral tubercles (27-33 vs 24-27), number of ventral scales (28-46 vs 33-44), number of precloacofemoral pores (35-45 vs 36-38), number of the lamella under the fourth toe (20-24 vs 19-22). This assignment is also supported by the similarity of the collected specimens with the type locality of *C. semicinctus*.

Cyrtodactylus semicinctus, C. marmoratus from Nunukan and *C. marmoratus* from Riau are grouped on the *C. marmoratus* from Martabe in all PC. The overlaping of *C. marmoratus* from Lampung, *C. marmoratus* from Riau, *C. marmoratus* from Nunukan and *C. marmoratus* from Kutai may be due to small

samples size. According to Rogell et al. (2020), this phenomenon can lead to an erroneous taxonomic conclusion. The position of these OTUs can be evident when the sample sizes for each OTU in sufficiently large, as suggested by Chan & Grismer (2021). Although *C. marmoratus* from Nunukan are overlapping within Martabe group, these species are distinct species according to Riyanto et al. 2021. *Cyrtodactylus marmoratus* from Nunukan is described as a new species namely *C. hamidyi*. These species are closely related to morphological characters within *C. matsuii*.

In this paper, we reported that *C. marmoratus* from Martabe has morphological variations compared to *C. marmoratus* from Java. In concordant, the comparison between *C. marmoratus* from Martabe and *C. agamensis* resulted that it has still unique morphological variations. *Cyrtodactylus marmoratus* from Martabe is easily distinguished from *C. agamensis* by fewer supralabial (10-12 vs 10-13), fewer infralabial (8-10 vs 9-12), widely dorsal tubercles (19-24 vs 17-21), fewer ventral scales (30-40 vs 50-67), a lower subdigital lamella on 4th toe (19-22 vs 21-26) (Milto & Bezman-Moseyko 2021).

Cyrtodactylus marmoratus group is a unique species regarding phylogenetic relationship and a gap-wide distribution (Riyanto et al. 2022). This group consists of four species, including *C. marmoratus, C. semiadii, C. papuensis* and *C. papeda* (Riyanto et al. 2022). *Cyrtodactylus marmoratus* group has potentially several undescribed species from Sumatra and Java (O'Conell et al 2019; Grismer et al. 2021). According to Riyanto et al. (2022) which stated that *C. marmoratus* is resticted to Java. It is indicated that specimens of *C. marmoratus* outside of Java island potential as a distinct species. Integrative taxonomic studies are needed to reveal hidden diversity on *C. marmoratus* and explain of phylogenetic relationship of this group.

CONCLUSION

The morphometric and meristic study of the *C. marmoratus* from Sumatra and Kalimantan revealed one suspected undescribed species, *C. marmoratus* from Martabe. Further study on molecular analysis is an ongoing issue to better understand phylogeny and reveal the taxonomic status of *Cyrtodactylus* in Sumatra and Kalimantan. The diagnostic charateristics to determine specimens to be *C. marmoratus* are the absence of tubercle on the upper arms, absence of enlarged median subcaudal, absence of tubercle on ventrolateral fold, vary in arrangement of precloaco femoral pores, absence of enlarged post cloacal scales, and presence of groove precloacal depression in male.

AUTHORS CONTRIBUTION

M.A.F. designed and conducted the research, analysed and interpretation the data, and wrote the draft of manuscript. A.R. designed the research, analysed and interpretation the data, reviewed the draft of manuscript, and supervised all the process. N.K. designed the research, reviewed the draft of manuscript, and supervised all the process.

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CONFLICT OF INTEREST

The authors declare there is no competing interest.

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