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Morphological variation of plantain squirrel *Callosciurus notatus* (Boddaert, 1785) (Rodentia: Scuriidae) population in West Sumatra, Indonesia

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Keywords: Bukit Barisan Mountain Range, *Callosciurus notatus*, morphological variation, squirrel

INTRODUCTION

Callosciurus notatus (Boddaert, 1785) is one of the squirrel species included in Scuriidae (Newak, 1999). The thing that distinguishes this squirrel with other species in the same genus was its habitat in the plantations area (Payne et al. 2000). This species is usually found in the plantations or secondary forest area, living and breeding in monoculture plantation (Francis 2008). *C. notatus* is a diurnal animal that is active during the day (Safid and Nordin, 2004). *C. notatus* has an average 175-223 mm body length, 160-210 mm tail length, 42-52 mm hind foot length, and 150-280 g body weight (Payne et al. 2000). The fur color-specific of this species is with brownish agouti on the upperparts and reddish-orange on the underparts that alter from very pale to fairly dark or sometimes with a gray wash. *C. notatus* has distinctive stripes on its flanks with the buff and black line (Francis 2008). *C. notatus* spread in Southeast Asia, including Thailand, Malaysia, Singapore, Sumatra, Java, Borneo, and several smaller surrounding islands (Tamura and Yong 1993). There are two subspecies (*C. n. vitatus* and *C. n. sapanensis*) in Sumatra and one subspecies each in Java and Kalimantan (*C. n. notatus* and *C. n. dalienensis*) (Martiny et al. 2002).

Morphometric studies of intra-specific or inter-specific variations by quantitative analysis are valuable for detecting patterns of geographic variations and delimiting intra-specific or inter-specific evolutionary units. Li et al. (2012), Hale and Luz (2003) revealed that there are morphological changes in British red squirrel (*Sciurus*

vulgaris) as a result of introduced species and changes in landscape management. Endo et al. (2004) observed the geographical variations of skull characters among *Callosciurus caniceps* populations in Thailand and found that the northern population had a larger skull size than the southern population in the continental mainland.

The wide distribution of this species was presumably followed by morphological variation among populations, including the population in West Sumatra. West Sumatra is a region in Sumatra Island crossed by Bukit Barisan mountain range that stretches from north to south of the island. Awarat et al. (1984) stated that the Bukit Barisan mountain range had formed during the early Paleocene (60 million years ago). The geographical factor variations between the east and the west area surely affected the ecological condition of each region. The highest peak of this mountain range is 3,865 m a.s.l.

C. notatus was found in lowland up to 1,500 m a.s.l. (Duckworth et al. 2008). The existence of Bukit Barisan mountain range might be a barrier separating *C. notatus* populations between the western and eastern areas. Therefore, the Bukit Barisan mountain range is likely to make a geographical barrier to the populations of *C. notatus*. Reece et al. (2011) stated that geographic separation could make the gene pool divergence and interrupted gene flow among the separated populations. This study aimed to analyze the morphological variations of *C. notatus* from four locations separated by the Bukit Barisan mountain range in West Sumatra.

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notatus was found in lowland up to 1,500 m asl (Duckworth et al. 2008). The existence of Bukit Barisan mountain range might be a barrier separating *C. notatus* populations between the western and eastern areas. Therefore, the Bukit Barisan mountain range is likely to make a geographical barrier to the populations of *C. notatus*. Reece et al. (2011) stated that geographic separation could make the gene pool divergence and interrupted gene flow among the separated populations. This study aimed to analyze the morphological variations of *C. notatus* from four locations separated by the Bukit Barisan mountain range in West Sumatra.

MATERIALS AND METHODS

Squirrels had been collected from four locations in West Sumatra, Indonesia, i.e.: Padang (9888602 S, 654200 E), Lubuk Basung (9971522 S, 605335 E), Sangir (9827689 S, 749274 E) and Baso (9969295 S, 665103 E) (Figure. 1). Squirrels were captured by using small mammal traps that were placed on the tree branches during the day. Jackfruit, coconut, peanut butter, and rambutan were used as baits. We recorded the age (sub-adult or

adult) and the sex of each squirrel captured. A total of 38 specimens (20 males and 18 females) were collected and used for morphological analyses. The number of specimens collected from each location was: Padang (4 males and 3 females), Lubuk Basung (10 males and 7 females), Sangir (3 males and 4 females), and Baso (3 males and 4 females). The specimens consist of 30 adults and 8 subadults. Specimens were deposited at the Museum Zoologi Universitas Andalas (MZUA).

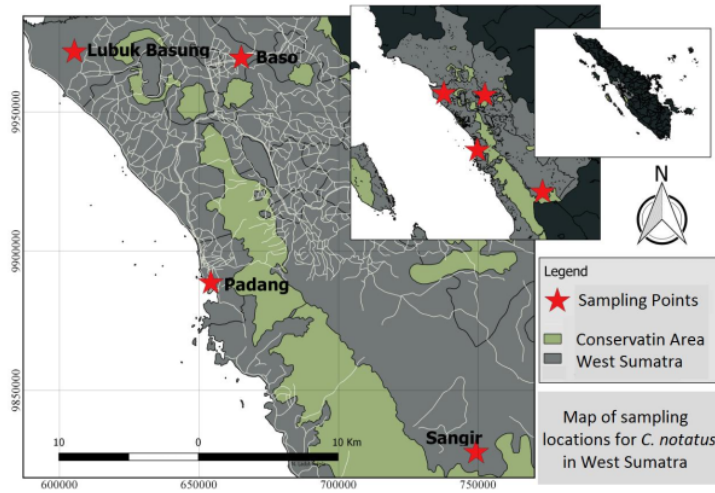


Figure 1. Map of sampling locations for *Callosciurus notatus* in West Sumatra, Indonesia. Padang and Lubuk Basung represented the western region of Bukit Barisan mountain range, while Baso and Sangir were located in the eastern region.

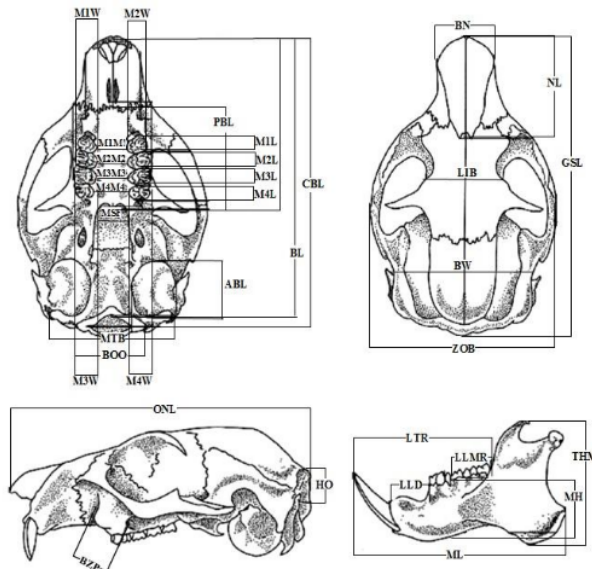


Figure 2. Skull characters were measured in this study (sketch modified from Li et al. 2012)

Procedures

There were 56 measured characters; 21 external characters and 35 skull characters. The external characters were measured by following Francis (2008) with addition of 17 characters. External characters measurements consist of: head and body length (HB), tail length (T), ear length (E), eye length (EL), interorbital distance (IOD), nose high (NH), nose width (NW), internarial space (IN), ulna length (UL), fore palm length (FP), first finger of forefoot length (1FFL), second finger of forefoot length (2FFL), third finger of forefoot length (3FFL), fourth finger of forefoot length (4FFL), tibia length (TL), hindfoot length (HF), first finger of hindfoot length (1FHL), second finger of hindfoot length (2FHL), third finger of hindfoot length (3FHL), fourth finger of hindfoot length (4FHL), fifth finger of hindfoot length (5FHL).

Skull characters were measured by following Martoyo et al. (2002), Song, Fa-Hong and Xue-Fei (2012), and consist of : maximum length of skull (GLS), nasal length (NL), nasal breadth (BN), zygomatic breadth (ZOB), length of first upper molar (M1L), width of first upper molar (M1W), distance between first upper molar (M1M1), length of second upper molar (M2L), width of second upper molar (M2W), distance between second upper molar (M2M2), length of third upper molar (M3L), width of third upper molar (M3W), distance between third upper molar (M3M3), length of fourth upper molar (M4L), width of fourth upper molar (M4W), distance between fourth upper molar (M4M4), palatal length (PL), length of palatal bridge (PBL), basal length (BL), condylobasal length (CBL), auditory bulla length (ABL), breadth of occipital condyles (BOO), mastoid breadth (MTB), least interorbital breadth

(LIB), braincase width (BW), mesopterygoid fossa breadth (MSF), occipito-nasal length (ONL), breadth of zygomatic plate (BZP), height of occipital (HO), mandible length (ML), height of mandible (THM), length of lower diastema (LLD), length of lower molar row (LLMR), length of lower tooth row (LTR), and mandibular height (MH).

Data analysis

The measurement data were divided by head and body length (external measurements) and the maximum length of the skull (skull measurements) to standardized character size of all specimens. Morphological variations among the population were analyzed using the Kruskal-Wallis test at a significance level of 5% using SPSS Ver. 17 software. MVSP 3.1 was used to analyzed Principal Component Analyses (PCA) and Cluster Analysis.

RESULTS AND DISCUSSION

Characters comparison among four populations showed significant differences among them in 10 external characters and nine cranial characters (Table 1).

Based on the analysis of 21 external characters and 35 skull characters, we obtained the Euclidean distance representing relationships based on the similarity of morphological characters among populations (Table 3). Analysis of UPGMA (Unweighted Pair Group Method Arithmetic Average) showed an overview of phenetics relationships among *C. notatus* populations (Figure 3).

Table 1. Comparison of *Callosciurus notatus* external characters from four populations in West Sumatra, Indonesia by Kruskal-Wallis test that showed significant results.

Characters	Population				Kruskal-Wallis Test
	Padang N=6	Lubuk Basung N=16	Sangir N=7	Baso N=7	
HB	185.0±9.8	191.1±7.5	183.7±8.9	196.9±3.8	H=10.372
	171.0-195.0	177.0-203.0	172.0-198.0	192.0-203.0	p=0.016
T	183.0±5.9	182.4±9.1	192.7±7.5	204.9±12.9	H=14.311
	174.0-190.0	165.0-195.0	185.0-203.0	183.0-225.0	p=0.003
E	18.2±1.2	17.7±1.2	18.6±0.9	18.1±1.3	H=10.105
	17.0-20.0	14.5-20.0	17.0-20.0	16.0-20.0	p=0.018
NH	7.5±0.8	6.2±0.6	6.6±0.7	6.2±0.6	H=14.237
	6.6-8.3	5.3-7.2	5.7-7.4	5.6-7.5	p=0.003
NW	8.4±0.3	7.9±0.7	7.6±0.9	7.8±0.4	H=8.784
	8.0-8.7	7.0-9.4	6.5-8.8	7.5-8.6	p=0.032
UL	38.3±2.3	37.6±2.0	38.6±2.3	39.6±1.6	H=11.942
	36.0-41.0	34.0-41.0	34.5-42.0	37.0-41.0	p=0.008
1FFL	10.8±0.7	11.1±0.6	11.9±0.6	11.1±0.9	H=9.572
	10.0-12.0	10.0-12.0	11.0-12.5	10.0-13.0	p=0.023
2FFL	14.3±2.3	14.1±0.7	15.0±0.6	14.1±0.1	H=9.696
	12.5-19.0	13.0-15.0	14.0-15.5	12.5-15.5	p=0.021
3FFL	15.5±2.2	15.1±0.7	15.8±0.4	15.3±0.6	H=10.314
	14.0-20.0	14.0-16.5	15.0-16.0	14.5-16.0	p=0.016
4FFL	11.7±0.5	11.7±0.9	12.2±1.0	11.8±0.5	H=8.989
	11.0-12.5	10.5-13.5	11.0-13.5	11.0-12.5	p=0.029

Note: The mean, standard deviation, maximum, minimum measurement in millimeters. (p significance ≤0.05; N: numbers of specimens)

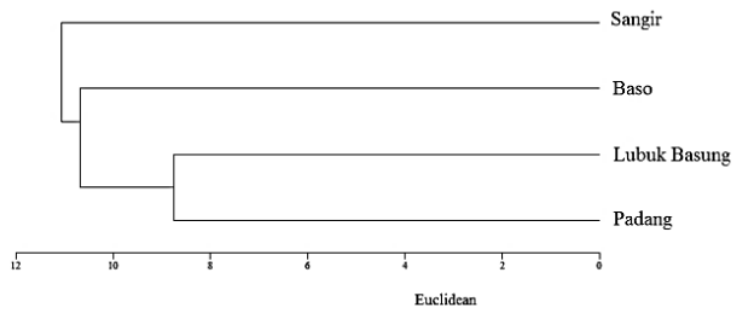
Table 2. Comparison of *Callosciurus notatus* skull characters from four populations in West Sumatra, Indonesia by Kruskal-Wallis test that showed significant results

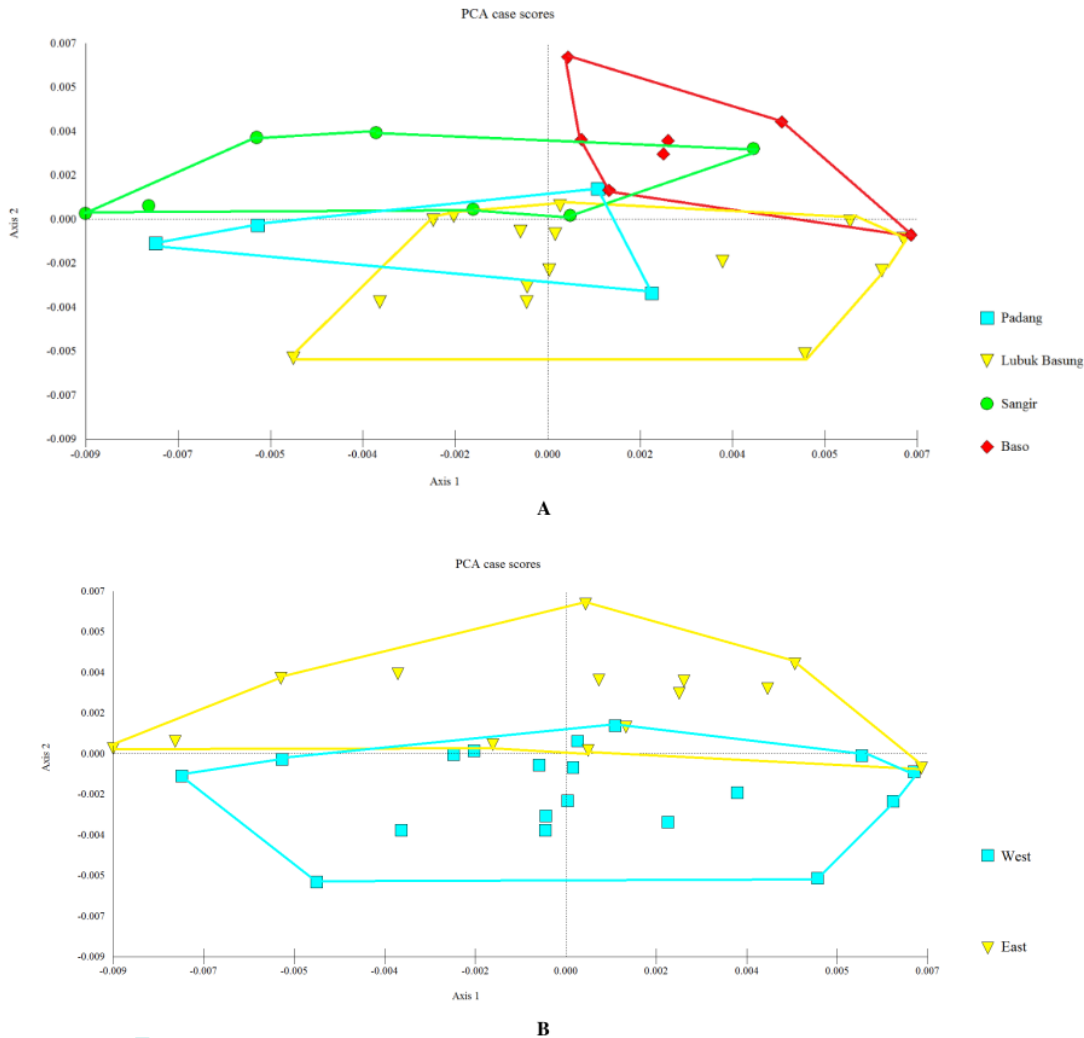
Characters	Population				Kruskal-Wallis Test
	Padang N=7	Lubuk Basung N=17	Sangir N=7	Baso N=7	
GSL	49.4±1.7 46.8-52.1	49.4±1.2 47.4-51.5	50.1±1.4 48.3-52.6	50.9±1.2 48.4-51.7	H=7.908 p=0.048
NL	14.9±1.0 13.2-16.3	15.1±0.7 13.9-16.0	14.3±0.6 13.2-15.3	15.0±0.5 14.1-15.4	H=14.862 p=0.002
MIL	2.0±0.1 1.9-2.1	2.0±0.1 1.8-2.1	1.9±0.1 1.8-2.1	1.9±0.1 1.8-2.0	H=9.001 p=0.029
BL	41.9±1.6 39.1-44.2	41.9±1.2 39.9-43.7	42.3±1.2 41.0-44.4	43.7±0.9 42.1-44.7	H=9.119 p=0.028
CBL	44.8±1.7 42.0-47.4	44.8±1.1 42.5-46.4	45.2±1.3 43.5-47.5	46.7±1.0 44.5-47.6	H=10.709 p=0.013
MTB	20.9±0.4 20.2-21.4	20.8±0.6 19.6-21.7	21.5±0.6 20.4-22.6	22.1±0.3 21.7-22.7	H=13.725 p=0.003
ML	32.1±1.2 29.9-34.0	32.2±1.0 30.3-33.6	32.0±0.9 30.6-33.3	33.3±0.4 32.3-33.6	H=9.545 p=0.023
THM	15.5±0.9 14.3-16.5	15.1±0.9 13.7-16.8	15.9±1.0 15.1-18.0	16.7±0.7 15.8-17.6	H=9.165 p=0.027
LLD	6.5±0.4 5.8-7.1	6.8±0.3 6.3-7.6	7.0±0.5 6.4-7.6	7.5±0.2 7.2-7.8	H=16.354 p=0.001

Note: The mean, standard deviation, maximum, minimum measurement in millimeters. (p significance ≤ 0.05 ; N: numbers of specimens)

Table 3. The Euclidean distance of *Callosciurus notatus*

Population	Padang	Lubuk Basung	Sangir	Baso
Padang	-			
Lubuk Basung	8,754	-		
Sangir	10,787	11,234	-	
Baso	10,900	10,461	11,160	-

**Figure 3.** UPGMA phenogram based on morphological characters of *Callosciurus notatus*



4 **Figure 4.** The plot of principal component 1 (PC1) versus principal component 2 (PC2) for the Principal Component analysis of *Callosciurus notatus* group. (A) Based on population group (B) Based on the east and west part of Bukit Barisan mountains range

Discussion

Kruskall-Wallis test showed that ten external characters were significantly different among populations. Those characters were head and body length (HB), tail length (T), ear length (E), nose high (NH), nose width (NW), ulna length (UL), first finger of forefoot length (1FFL), second finger of forefoot length (2FFL), third finger of forefoot length (3FFL) and fourth finger of forefoot length (4FFL). Characters on the finger are more differentiated than other characters. The fingers are one part of the squirrel body used to climb. Based on the measurement results, the finger sizes of Sangir population were generally longer than those of Lubuk Basung and Baso populations. The differences

were likely affected by the adaptation of *C. notatus* in Sangir that lived in an area large arbor plant as well as being near to the secondary forest whereas *C. notatus* populations founded in Lubuk Basung and Baso were located at the plantation area with palm trees and cacao.

Li et al. (2012) stated that the phenotype divergence may have regard to the geographical distribution and living conditions, and can serve as a reflection of the adaptation form of the different ecological niches. Hansson and Henttonen (1988) reported that the populations of the same species in different habitats could indicate variations due to the influence of extrinsic factors. One factor that may have

significant influence is food. Pizzimenti (1980) stated that there is a relation between diet habits and morphology.

The skull characters that showed variation on the four *C. notatus* populations were the maximum length of the skull (GLS), basal length (BL), condylobasal length (CBL), and mastoid breadth (MTB). These characters affect or are affected by the size of the brain. While the other skull characters with differentiation such as nasal length (NL), length of first upper molar (M1L), mandible length (ML), the height of mandible (THM) and length of lower diastema (LLD) may be more dominated by the type of food. Velhagen and Roth (1997) suggest that the arboreal squirrel usually shows the most substantial mechanical advantage on incisors used to eat fruits and nuts. Hayashida et al. (2007) argued that skull variations of *Callosciurus caniceps* are influenced by geographical differences.

According to the Euclidean distances, *C. notatus* populations that have the most similarities were between Padang and Lubuk Basung population, while populations that have the least morphological similarities were between Lubuk Basung and Sangir population. Based on those values we can infer that geographical distance relatively reflected the relationship distance among populations. Padang population is closer geographically to Lubuk Basung population, while the geographical distance between Lubuk Basung and Sangir is the furthest compared to the other sampling locations.

The phenogram (Figure 3) shows that the morphological similarities between populations were relatively related to the geographical distance and geographical location of the sampling sites that were separated by Bukit Barisan mountain range. Map of sampling location (Figure 1) illustrates that Padang is closer geographically to Lubuk Basung. Both locations are also located on the western side of Bukit Barisan. However, *C. notatus* population from Baso and Sangir tend to have higher Euclidean distances although both locations are on the east side of Bukit Barisan. It is also reinforced by the phenogram which does not show the same cluster between Sangir and Baso. Even *C. notatus* from Baso has more similarities to Lubuk Basung population that is closer geographically in distance than to Sangir population. Sangir population tends to have more similarities with Padang population that is also closer in geographical distance.

In addition to the geographical distance, the populations of *C. notatus* that were found in similar environmental conditions also showed similarities in morphological characters. Sangir and Padang population, which are both located on the areas of the fields and adjacent to the secondary forest comparatively had more similarities than Baso, and Lubuk Basung population had. While Baso and Lubuk Basung populations, which are both located on the vast plantations areas, had similarities too. Therefore, the presence of Bukit Barisan mountain range does not entirely affect the similarity or differentiation of morphological characters among populations of *C. notatus* in West Sumatra. There are other factors such as geographical distance and environmental conditions, like available food resources and habitat vegetation, which probably influence

the similarity of morphological characters among populations in West Sumatra.

The natural barrier of geographical distance is related to gene flow from separated populations. Andrews (2010) stated that gene flow, genetic drift, and natural selection do not act in isolation in the fragmented habitat. The obstruction of gene flow will result in genetic homogeneity within a metapopulation, promoting the population divergence, and, if continuously, can end up to speciation. Moncried (2015) reported that morphological differentiation in fox squirrels and gray squirrels had been influenced by the lower Mississippi River valley that had been preventing gene flow of these species.

Kramm, Marki, and Glime (1975) reported that morphological characters between populations of red squirrels (*Tamiasciurus hudsonicus*) in the area of Lake Superior were also influenced by geographical position. The closer geographical distance, the more similarities of morphological characters it had. Barrett and Schluter (2008) stated that the dynamics and different results of adaptation were affected by the variation source. The variations that occur are very related to how the population can respond to environmental change.

The PCA analysis showed the distribution of individuals from each population based on morphology, which is the loading or deciding factor. The ordination of plots (Figure 4) has shown that there are two groupings of *C. notatus* samples which describe the distribution of populations in the west and east side of Bukit Barisan. Character variation in populations of *C. notatus* in the parts of east and west possibly caused by the difference in environmental conditions that are the result of the formation of the Bukit Barisan since millions of years ago.

Anwar et al. (1984) report that Sumatra that was divided into two sides by the Bukit Barisan has a different ecological condition. The factors such as geomorphology, vegetation, climate, rainfall, and soil variation between the west and east area have impacted the ecology in both separated sides. Colombijn (2005) stated that the Bukit Barisan has two unequal parts that form the narrow coast and the wider half of hills in the west part and alluvial lowland in the opposite part.

Yu (2002) reported that the morphological and genetic differentiation among some populations of flying squirrels (e.g. *Eupetaurus*, *Eoglaucomys*, *Hylapetes*, and *Petaurista*) occur in line with the geographical variations along the Trans-Himalaya mountain chain that caused of the climate change during the Pleistocene, and also became occurrence of physical barriers to migration. Research by Endo et al. (2003) on the skull variations of *Dremomys rufigenis* in three geographical locations consisting of Peninsular Malaysia, Viet Nam, Laos and Thailand showed variations affected by the existence of the Isthmus of Kra as a geographical barrier.

In conclusion, variation of morphological characters of *C. notatus* in several populations in West Sumatra was found in ten external characters and nine skull characters from a total of 56 characters measured. Body and tail length characters that had a relatively longer length ratio were found in Baso population. Character lengths of ears

and extremities (ulna and digiti length) which relatively had a longer ratio were found in the Sangir population. Skull morphological characters that showed significant differences were generally found in Baso populations having longer ratio values than other populations. Based on the results of this study it is hoped that further study will be carried out to determine what environmental factors specifically influence certain morphological characters.

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