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Are the mandible shapes of common (Paradoxurus hermaphroditus) and golden (Paradoxurus zeylonensis) palm civets different? A pilot study

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Abstract: In this study adult common and golden palm civet mandibles were analysed by geometric morphometric method. For this purpose, the materials were photographed in accordance with the procedure and analysed using computer programs. No allometric component was detected in the comparison of the mandibles. The first principal component defined 28.657% of the total shape variation in the mandibles of the two groups that were analysed with a total of 19 landmarks. The samples were largely separated from each other in the principal component analysis. The shape differences were mostly in the caudal of the mandible. Also, in the common palm civet mandible, the mental foramina were located more ventrally from the premolars edge than in the golden palm civet. It is thought that the information obtained as a result of the study will contribute to the studies of understanding the taxonomic difference or similarities in terms of two species.

Key words: Geometric morphometry, mandible, MorphoJ, principal component analysis

1. Introduction

Paradoxurus [1] is a genus belonging to the family Viverridae of the order Carnivora [2]. This genus includes three breeds: golden palm civet (Paradoxurus zeylonensis, PZ, Sri Lanka), brown palm civet (Paradoxurus Jerdoni, PJ, Indian Western Ghats), and common palm civet (Paradoxurus Hermaphroditus, PH, South and Southeast Asia). These species are mostly nocturnal and fruit-loving animals. The palm civets also consume species such as insects, worms, mollusks and small vertebrates [3].

The determination of shape differences by statistical analysis of coordinates of homologous landmarks is possible with the geometric morphometry (GM) method [4-6]. Geometric morphometry is a method that can determine phylogenetic relationships in mammalian skulls or mandibles [7-11]. Common and golden palm civets can be easily distinguished from each other by their phenotypic characteristics (hair colour, head width, etc.) [12]. However, the benefit that can be obtained from this distinction is limited to current forms. Therefore, in order to make inferences about the past of the civet, it is necessary to elaborate the analysis on the bones of the current forms. In the study, it was aimed to investigate the common and golden palm civet mandibles by geometric morphometric method, and the answers to the following questions were sought:

- To what degree are the shape differences or similarities between the mandibles of the two civet species?
- If there are differences in shape, at which points of the mandible are these differences concentrated?
- Can shape differences be used to distinguish between two civet species? Could these perhaps be considered pilot study findings?

2. Materials and methods

2.1. Materials

In the study, 7 common (PH) and 11 golden palm civet (PZ) mandibles of adults were used. Materials were obtained from different regions of Sri Lanka (Table 1, Figure 1). There were no pathological conditions in these samples.

2.2. Geometric morphometric analysis

Palm civet's left mandible was photographed laterally, focusing on the fourth premolar tooth. Mandibles were photographed from a distance of 20 cm. Nineteen homologous landmarks were defined on the photographs

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Table 1. Locations of animals obtained from Sri Lanka.

Individuals No	Place
PZ1	Knuckles Walpolamulla
PZ2	Knuckles Illukkumbura
PZ3	Sinharaja Pitakele
PZ4	Kurunegala Boyagoda
PZ5	Matale Rattota
PZ6	Bibile Lunugala
PZ7	Thabana Monaragala
PZ8	Knuckles Illukkumbura
PZ9	Thabana Monaragala
PZ10	Nuwaraeliya Hagalla
PZ11	Kandy Lake round
PH1,2,3,6,7	Katubedda
PH4	Knuckles Meemure
PH5	Pannala

PH: Paradoxurus hermaphroditus, PZ: Paradoxurus zeylonensis.

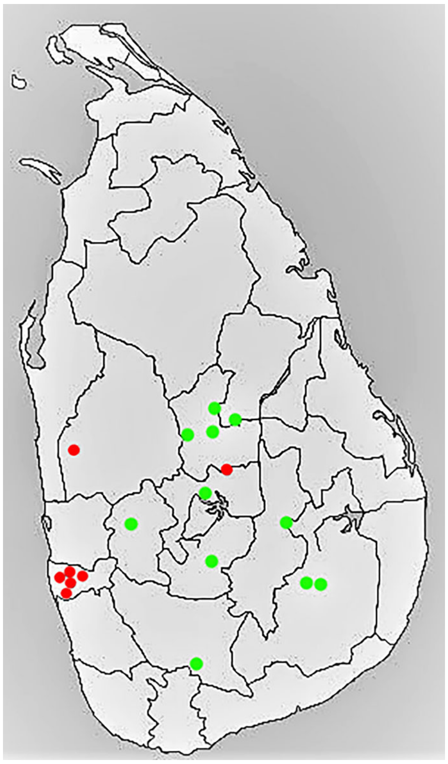

Figure 1. Locations of animals obtained from Sri Lanka. Red: common palm civet, green: golden palm civet.

(Figure 2). These landmarks were marked in the TpsUtil (Version 1.79) [13] and TpsDig2 (Version 2.31) [14] programs. As a result, x and y Cartesian coordinates of homologous anatomical points in the mandible were determined. TpsSmall (version 1.34) program was used to determine the accuracy of the landmarks [15]. Accordingly, the uncentred correlation value was determined as 1.000000, while the root mean square error value was determined as 0.000005. These results proved that the landmarks were marked correctly.

2.3. Statistical analysis

Superimposition of the mandibles was achieved by performing General Procrustes analysis (GPA) in order to eliminate the differences in the position, placement or size of the mandible in the photographs. In the study, PCA analysis was performed on the new coordinates obtained by GPA to determine the shape variation between groups. Thus, the degree of separation of the samples according to the group was determined by using covariance analysis among the factors [16]. In the principal component analysis, the results were determined as a percentage value and how the samples were separated from each other was shown on the graph. Two t-tests were performed to compare the Procrustes coordinates between groups. MorphoJ program was used to determine the points of shape differences in the mandible [17]. Principal component analysis and classical cluster analysis (CA) were performed in PAST (Version 4.02) program [18]. Allometry and canonical variance analysis (CVA) were performed in MorphoJ program.

3. Results

The reports of principal components analysis were presented in Table 2. There were 17 principal components in total. It was found that 28.657% of the total shape variation was explained by the first principal component and the first three principal components explained 61.089% of the total shape differences. An evident difference in refraction was observed between the first and second principal components. The distribution of individuals according to the first principal component was shown in the graph in Figure 3. A sample (PZ2) took place at the intersection of the groups with reference to first principal component (PC1) graph. PH samples (approximately 57%) were clustered more in the second region (x: –, y: +), while PZ samples (approximately 54%) were more clustered in the fourth region (x: +, y: –).

The hierarchical distribution of individuals was shown in the graph in Figure 4. In this graph, it was seen that individuals other than PH1 (Number one common palm civet) and PZ1 (Number one golden palm civet) were concentrated in their own groups.

The Procrustes coordinates of the two civet groups were statistically significant. These results are presented in Table 3. In this table, the statistical differences were seen in y coordinates in LM1, LM2, LM3, LM12, LM16, and

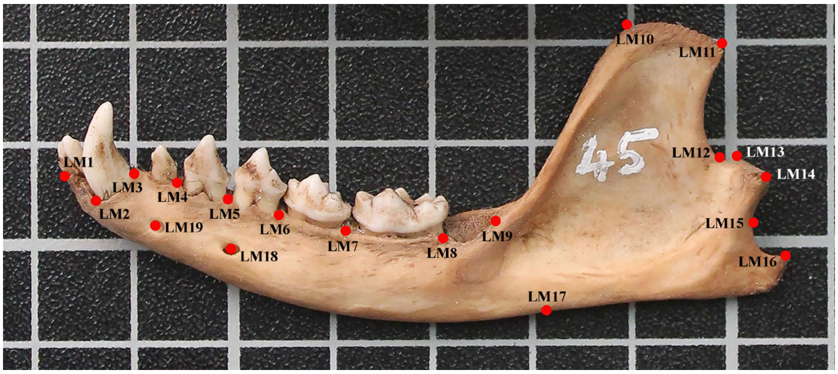

Figure 2. Landmarks, **LM1:** the most oral edge of the incisive teeth, **LM2:** anterior edge of canine, **LM3:** posterior edge of canine, **LM4:** posterior edge of P1, **LM5:** posterior edge of P2, **LM6:** posterior edge of P3, **LM7:** posterior edge of P4, **LM8:** posterior edge of M1, **LM9:** posterior edge of M2, **LM10:** anterior corner of coronoid process, **LM11:** posterior corner of coronoid process, **LM12:** mandibular notch, **LM13:** anterior edge of condyloid process, **LM14:** posterior edge of condyloid process, **LM15:** the midpoint of margo caudalis on mandible, **LM16:** angular process, **LM17:** flattening point of ventral edge of mandible, **LM18:** posterior mental foramen, **LM19:** anterior mental foramen (LM: landmark, P: premolar tooth, M: molar tooth).

Table 2. Results of the principal component (PC) analysis.

PC	**Eigenvalue**	**% Variance**	**PC**	**Eigenvalue**	**% Variance**
1	0.000494305	28.657	**10**	3.43148E-05	1.9893
2	0.000357048	20.699	**11**	2.88908E-05	1.6749
3	0.000202394	11.733	**12**	1.90369E-05	1.1036
4	0.000155598	9.0206	**13**	1.53437E-05	0.88952
5	0.000128276	7.4366	**14**	1.2374E-05	0.71737
6	0.000102448	5.9392	**15**	8.01031E-06	0.46438
7	5.80275E-05	3.3641	**16**	5.44317E-06	0.31556
8	5.52011E-05	3.2002	**17**	3.33305E-06	0.19323
9	4.4884E-05	2.6021			

LM19, and in x coordinates in LM14, LM15, LM16, and LM17.

Regression analysis was performed to determine the predictability of mandible size related changes of shape in civets. According to this results, a rate of 5.6913% was obtained (p: 0.4805 at 95% confidence interval). In civet groups, 18.6982% of the shape determined by the first principal component could be predicted by size (p: 0.0507). No allometric component was found. These results proved that variations in mandible shape were not dependent on size.

The shape differences of the landmarks that marked on the mandible were specified in Figure 5 according to the first and second principal components. These differences in the first principal component became evident in LM10, LM11, LM15, LM16, LM17, and LM19. The distinct shape differences in the second principal component were in LM7, LM8, LM9, LM10, LM11, and LM17.

The localization of the civet mandibles within the canonical variant was determined by canonical variance analysis. As a result of this analysis, the landmarks of the shape in first canonical variance (CV1) and the first principal component (PC1) were largely similar. Mahalanobis distances were determined as 3.3874 and Procrustes distances as 0.0262 (p: 0.0003). Shape differences (in wire-frame warp graph) detected in the civet mandibles according to the groups were presented in Figure 6. In this graph, homogeneous distribution of frequency between groups was observed. The mandible of the common palm civet was higher at the mandibular ramus level than the golden palm civet. In the common palm civet mandible, the mental foramina were located

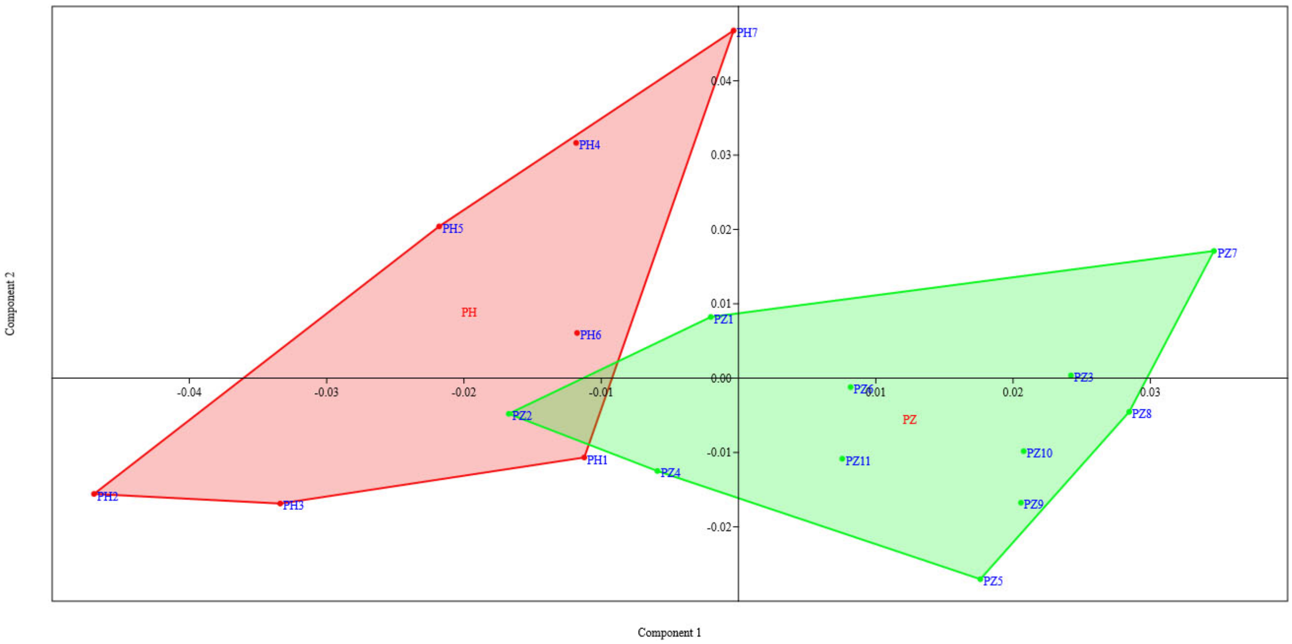

Figure 3. Graphical representation of the civet mandibles according to the first principal component. Red: common palm civet, green: golden palm civet.

more ventrally from the premolars, and the mandibular notch was sharper than in the golden palm civet.

4. Discussion

In the study, the mandibles of two civet species belonging to the genus Paradoxurus were examined by geometric morphometric methods. In this study, firstly, the effect of taxonomic relationship on the shape of the mandible was tried to be determined. Although the number of materials was initially considered sufficient, the inability to standardize living conditions constituted the limit of the study. Considering the degree of difficulty associated with conducting scientific studies on exotic species, conducting such a study may present difficult information to the literature. This shows that the limits of the study are at a tolerable level.

Members of the order Carnivora can be grouped into hypercarnivores, insectivores, omnivores, fish eaters, and herbivores. Therefore, this team has a wide range of dietary habits. Studies have shown that allometric and phylogenetic models result from shape-function relationships [11]. The mandible is a bone that is responsible for catching, piercing, cutting and shredding food. Therefore, diet and nutritional behaviour are closely related to the shape of the mandible [19, 20]. In addition, the chewing muscles that provide the movement of the mandible also affect the mandibular growth morphology [21]. The synchronized movement of the chewing muscles controls the jaw movement and chewing force [22].

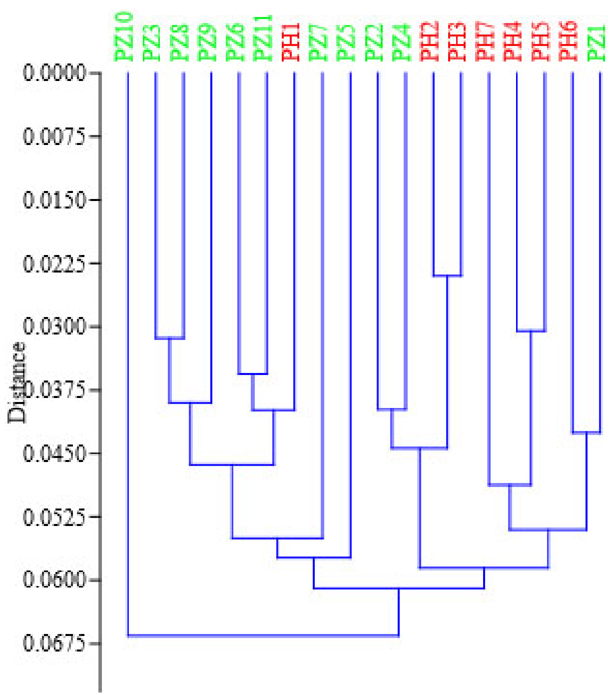

Figure 4. Hierarchical graph of civets. Red: common palm civet, green: golden palm civet.

Gürbüz et al. [9] compared the wolf and dog mandibles of the order Carnivora with the geometric morphometric method and found that the shape differences were more

Table 3. Statistical analysis of the two t-test of the landmark coordinates.

Landmarks	**x**	**y**
LM1	NS	S (0.00638136)*
LM2	NS	S (0.0358)*
LM3	NS	S (0.002646)*
LM12	NS	S (0.044127)*
LM14	S (0.043842)*	NS
LM15	S (0.0056086)*	NS
LM16	S (0.0026775)*	S (0.038242)*
LM17	S (0.00045353)*	NS
LM19	NS	S (0.002797)*

NS: no significant, S: significant, *: p values.

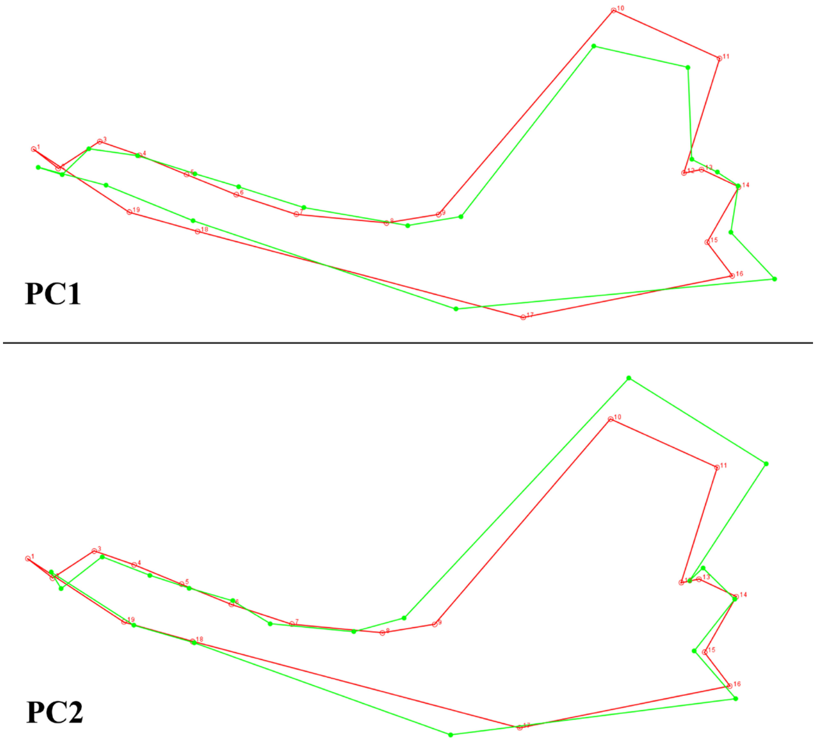

Figure 5. Wireframe graph in first and second principal components (PC1 and PC2). The red plots indicate the positive limit of the PC1 and PC2.

concentrated in the mandibular ramus according to the first principal component. Hadžiomerović et al. [23] determined the shape change of the mandible between the red fox and golden jackal using 10 landmarks. In their study [23], it was stated that the ventral edge of the mandible is more convex in the golden jackal, while the dental arch is longer in the fox. They also reported that the condyloid process of the jackal is wider and stronger, and the angular process was angled more sharply in jackal than in fox. In our study, similar to the literature [9, 23], the most shape variation was observed in the landmarks representing the caput, ramus and mandibular angle between the two civets species. Considering that the nutritional habits are similar for the two civet species, these differences may be significant in terms of taxonomic distinction.

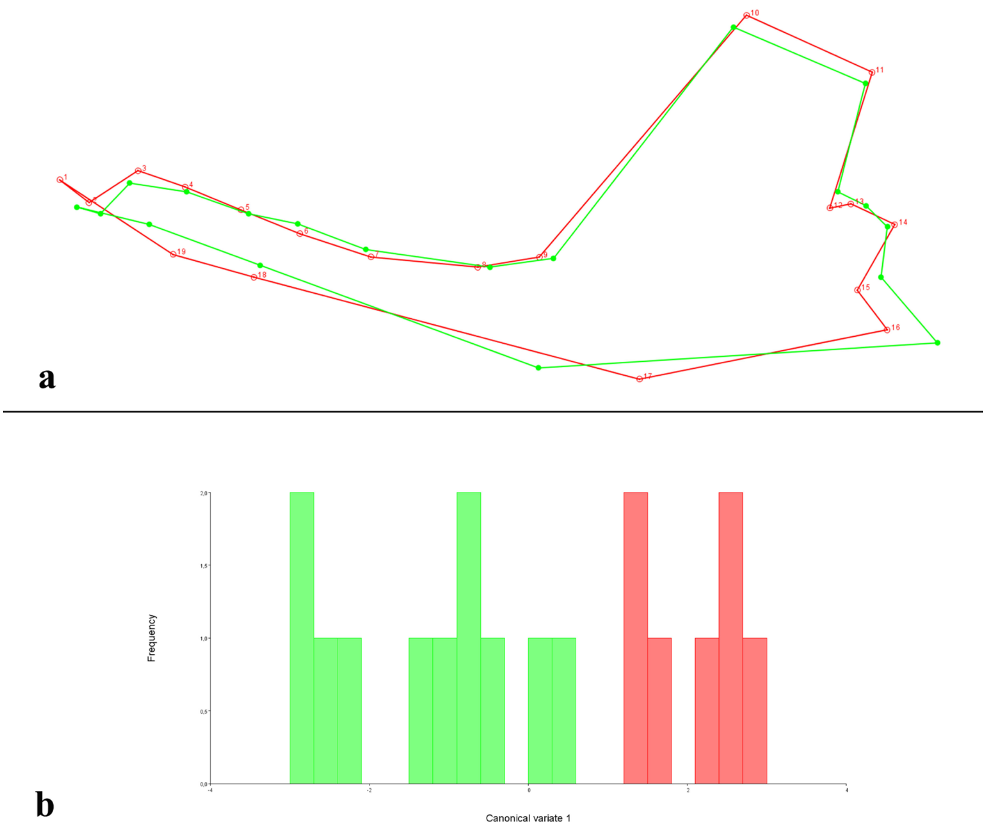

Figure 6. The results of the shape differences of mandibles by canonical variance analysis. a: wireframe warp graph, b: frequency graph, red: common palm civet, green: golden palm civet.

In conclusion, the shape of the mandible in common and golden palm civets was similar at the points representing tooth level but different at points where the masticatory muscles are functional. An important point in terms of shape difference was that the mental foramina in the common palm civet were located more ventrally from the premolars edge than in the golden palm civet. This was noted as a significant difference considering the inability to detect an allometric component. When all the findings of the study were evaluated, it was concluded that the mandibles of the two civet breeds could be used in taxonomic distinction. However, it can be offered as a suggestion to reach more comprehensive data by increasing the number of materials and including brown palm civet samples.

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