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Sexual dimorphism in external morphology and pelvis of the lesser bandicoot rat, *Bandicota bengalensis* (Gray, 1835) (Mammalia: Rodentia: Muridae)

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Abstract

We used linear morphometric measurements to assess secondary sexual dimorphism in the external traits and pelvis of the lesser bandicoot rat, *Bandicota bengalensis* (Gray). Multivariate analysis of variance revealed significant difference between the sexes in both external (Wilks' lambda = 0.542, F = 3.378, P < 0.05) and pelvis measurements (Wilks' lambda = 0.238, F = 10.05, P < 0.05). Males were larger than females in most of the external traits. In contrast, females were larger in most variables of the pelvis. Separation between the sexes was also demonstrated in the discriminant analysis. Although allometric slopes did not differ between the sexes, means adjusted for allometry were sexually dimorphic in five out of seven variables of the pelvis. In conclusion, our results revealed differential patterns of secondary sexual dimorphism for the external morphology and pelvis in *B. bengalensis*. These patterns are explained with respect to the accessible evolutionary theories on mammalian sexual dimorphism.

Key words: *Bandicota bengalensis*, external traits, morphometrics, pelvic girdle, sexual dimorphism

Introduction

The lesser bandicoot rat *Bandicota bengalensis* (Gray, 1835) is a medium-sized terrestrial murid rodent with a tail shorter than its head–body length (Chakma, 2009; Rao et al., 2019). The face is comparatively rounded with a broad muzzle and pinkish round ears (Chakma, 2009). It typically burrows in humid soil (IUCN Bangladesh, 2015; Rao et al., 2019). It prefers cultivated lands; however, it inhabits a wide range of habitats including bunds and edges of wetlands, gritty soil with high moisture content in cultivated plains, gardens, pasture lands, wastelands, and warehouses in human habitations (Chakma, 2009; Rao et al., 2019). Its diet consists of wheat, rice, grains, sugarcane, beans, fruits, vegetables, mollusks, and crabs (Khairuddin et al., 2011). It is native to Bangladesh, India, Malaysia, Myanmar, Nepal, Sri Lanka, and Thailand (IUCN Bangladesh, 2015). In Bangladesh, it is widely distributed (Khan, 2008; Chakma, 2009). This species is considered a pest to various crops and stored grains in Bangladesh and other countries (Aplin et al., 2003; IUCN Bangladesh, 2015).

Morphometrics, the field of biological size and shape analysis, investigates how the shape of organs and organisms varies and how their covariation relates to other variables (Slice, 2007; Reyment, 2010; Parés-Casanova, 2017). Size and shape comparisons have long been of interest to biologists and are now addressed as the key aspects in morphometrics (Zelditch et al., 2004). Morphometric techniques quantitatively examine the variation of morphological characteristics of organisms as well as evolutionary links, developmental changes in form, and the effect of mutations on shape (Claude, 2008; Parés-Casanova, 2017; Coker et al., 2020).

Secondary sexual dimorphism is the difference in body characteristics between males and females of the same species (Issac, 2005; Biswas et al., 2020).

In vertebrates, sexual dimorphism is a common phenomenon (Crook, 1972; Ralls, 1977; Parker, 1992; Weckerly, 1998; Schulte-Hostedde et al., 2000, 2001; Issac, 2005). It has become an alluring topic for evolutionary biologists due to its prevalence in animals (Schulte-Hostedde et al., 2001; Issac, 2005; Nandini, 2011). There are a variety of ways in which the sexes of mammalian species differ from one another (McPherson and Chenoweth, 2012). The overall body size and specific morphological traits of an organism are usually subject to natural selection (Andersson, 1994; Szekely et al., 2007; Nandini, 2011). In most mammals, male-biased sexual dimorphism prevails, whereas female-biased sexual dimorphism is found in cetaceans, bats, and flying squirrels (Schulte-Hostedde, 2007; Nandini, 2011; Biswas et al., 2020).

External morphological traits are important in species descriptions because they help to comprehend the function, evolution, and flexibility of the forms of an organism (Ramirez-Portilla et al., 2022). The size of an animal's body is one of the most important physical characteristics that affects its behavioral activities and ecological progress (Ralls, 1977). Therefore, the external morphological characteristics of an animal serve as indicators of its biology, ecology, and social behavioral patterns (Kent, 2010).

The mammalian pelvis consists of three bones in each halve—pubis, ilium, and ischium (Matysiak et al., 2017). The two halves (right and left) of the pelvis ventrally connect at the pubic symphysis and on the dorsal side with sacral vertebrae through the ilium (Rommel and Reynolds, 2009). The ischium and pubis are generally situated at the ventral part of the ilium. The obturator foramen, an opening part of the pelvic girdle, is located at the posteroventral part of the pelvis, and is surrounded by all three bones (Rommel and Reynolds, 2009; Matysiak et al., 2017). In most mammalian species, the pelvis is typically sexually dimorphic in relation to both size and shape (Berdnikovs et al., 2007). In species where males have a larger femoral size, females are typically larger in pelvis size than males (Schultz, 1949; Tague, 2005). Pelvic dimorphism typically exists even in species having a small difference in body size and shape between the sexes (Krystufeq, 1998; Schutz et al., 2009; Matysiak et al., 2017).

B. bengalensis has been studied in Bangladesh by several researchers (Brooks et al., 1985; Khalequzzaman and Hossain, 1999; Hossain and Khalequzzaman, 2000), who mostly focused on its ecological aspects. The taxonomical features of *B. bengalensis* have been studied by many researchers (Ellerman, 1961; Musser and Brothers, 1994; Aplin et al., 2003; Singh et al., 2011; Pimsai et al., 2014; Pacheco, 2019; Rao et al., 2019). Moreover, Krystufek et al. (2016) reported non-significant sexual dimorphism in the cranium, mandible, and molars of *B. bengalensis*. Although some morphometric information is available on male and female bandicoot rats (Singh and Sangha, 2015), no previous study has analyzed the patterns of sex differences in the external morphology and pelvis of *B. bengalensis* in detail. Since natural selection and variability are intimately connected, measures of variation are the key component in evolutionary studies (Biswas and Motokawa, 2019). Therefore, this study is an attempt to examine the sex differences in the external morphology and pelvis of *B. bengalensis* using different statistical analyses.

The major objectives of this study were to (1) analyze the patterns of differences in external morphological traits between males and females of *B. bengalensis*, (2) investigate the variation between the male and female pelvis, and (3) focus on the possible factors related to those patterns of dimorphism in *B. bengalensis* from the Chittagong University campus and its surrounding areas of Bangladesh.

Material and Methods

Specimens and morphometric measurements

A total of 31 adult specimens (12 males and 19 females) of *B. bengalensis* were used for external morphological measurements, whereas 30 specimens (11 males and 19 females) were used for pelvic measurements (Fig. 1). The specimens were identified as *B. bengalensis* based on taxonomic keys by Blanford (1891) and Aplin et al. (2003). We used specimens collected from the Chittagong University campus and its surrounding area from November 2021 to July 2022; these were already trapped by local people. Moreover, we also captured some live specimens using metal cage traps (Onwuama et al., 2012). The trapped specimens were euthanized using chloroform in the enclosed container (Onwuama et al., 2012). The guidelines of the American Society of Mammologists were followed for trapping and handling the animals (Gannon et al., 2007; Shintaku et al., 2010). All protocols of this study were approved by the Animal Ethics Review Board of the Faculty of Biological Sciences, University of Chittagong (reference number – AERB-FBSCU20230202-(1)).

Sexes were determined by the presence of mammary glands in females and penis in males (Shoma et al., 2015). The age of each specimen was verified based on the eruption and wear of the molar teeth (Carleton and Musser, 1989; Voss and Marcus, 1992). With some modifications, six external morphometric measurements were taken following Shintaku et al. (2012) (Table 1; Fig. 2). Pelvic bones were prepared using both a boiling process (Auffray et al., 2011) and chemical maceration (Onwuama et al., 2012) with some modification. Seven morphometric measurements were taken for the pelvic girdle following several previous studies (Kuncova and Frynta, 2009; Balciauskiene and Balciauskas, 2016; Matysiak et al., 2017) (Table 1; Fig. 3).

The measurements of the head–body length, as well as the tail length, were taken with a scale and measuring tape, whereas other measurements were taken using a slide caliper adjusted to the nearest 0.1 mm.

Morphometric analyses

Summary statistics (arithmetic mean (M) and standard deviation (SD)) were calculated for all measurements of the external morphology and pelvis. Based on log-transformed data, we conducted multivariate analysis of variance (MANOVA) to examine the overall sex differences in the external traits and pelvis (Biswas and Motokawa, 2019). Moreover, sexual size dimorphism (SSD) was estimated using the following formula: SSD = M/F, where M is the mean value of males and F is the mean value of females of morphometric traits (Smith, 1999). The Mann–Whitney *U*-test was used to investigate differences in each variable between the sexes (Prevosti and Lamas, 2006; Biswas and Motokawa, 2019).

Figure 1: The lesser bandicoot rat, *Bandicota bengalensis* in dorsal (A) and ventral (B) views.

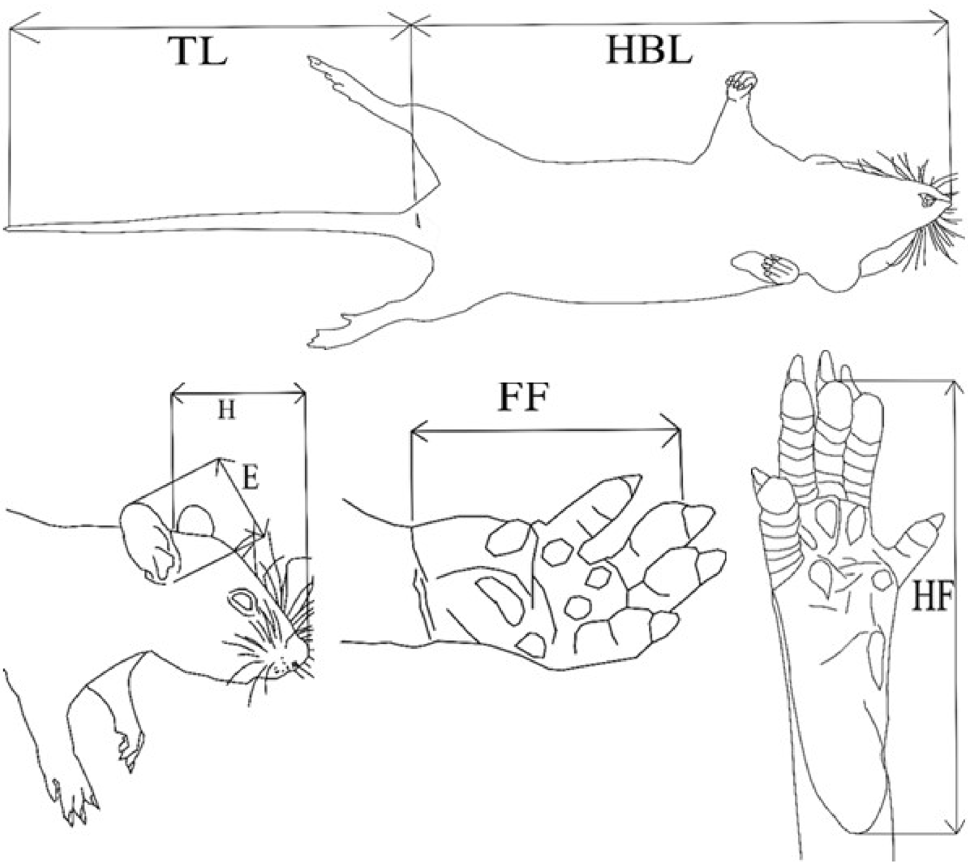

Figure 2: External measurements (HBL: head–body length; TL: tail length; H: head length; E: ear length; FF: forefoot length; and HF: hindfoot length) used in *Bandicota bengalensis*.

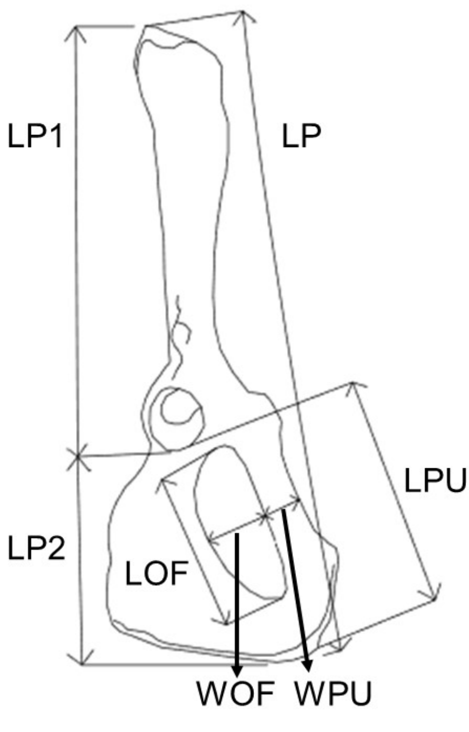

Figure 3: Pelvis measurements (LP: length of pelvis; LP1: length of ilium; LP2: length of ischium; LPU: greatest length of pubis; LOF: length of obturator foramen; WOF: width of obturator foramen; and WPU: width of pubis) used in *Bandicota bengalensis*.

Table 1: List of external and pelvis measurements and abbreviations for *Bandicota bengalensis.*

	Abbreviation	Measurement
External Morphology	HBL	Head and body length
	TL	Tail length
	HF	Hindfoot length
	FF	Forefoot length
	H	Head length
	E	Ear length
Pelvic Morphology	LP	Length of pelvis
	LP1	Length of ilium
	LP2	Length of ischium
	LPU	Greatest length of pubis
	WPU	Width of pubis
	LOF	Length of obturator foramen
	WOF	Width of obturator foramen

Principal component analysis (PCA) was carried out based on the correlation matrix of log-transformed data to determine the intraspecific morphological variation (Motokawa et al., 2003; Biswas et al., 2020). We conducted a linear discriminant analysis (LDA) to examine the overall distinctiveness between the sexes (Fernández-Arjona et al., 2017; Biswas and Motokawa, 2019). The sexes were also compared using an analysis of covariance (one-way ANCOVA) based on log-transformed variables that showed significant correlation with head–body length (HBL) and length of pelvis (LP) for external morphology and pelvis, respectively (Motokawa et al., 2003; Biswas and Motokawa, 2019). All analyses were run using the software PAST (ver. 4.12b) (Hammer et al., 2001).

Results

Sexual dimorphism in external morphology

The MANOVA revealed significant difference between the sexes (Wilks' lambda = 0.542, F = 3.378, P < 0.05). Descriptive statistics showed that males had slightly larger mean values for most of the external variables than females (Table 2). Slightly larger mean values were observed for tail length (TL) and ear length (EL) in females than in males (Table 2). The range of SSD was from 0.997 (TL) to 1.043 (hindfoot length (HF)) (mean: 1.015 ± 0.018; n = 6) (Table 2). The Mann–Whitney U test showed a significant difference between the sexes in HF (U = 34.5, P < 0.05), which was significantly larger in males than in females.

Sexual dimorphism of the pelvis

As the Mann–Whitney U test showed non-significant difference between the right and left side variables (LP (U = 440.5, P > 0.05), LP1 (U = 408, P > 0.05), LP2 (U = 392, P > 0.05), LPU (U = 419.5, P > 0.05), WPU (U = 447, P > 0.05), LOF (U = 434.5, P > 0.05), and WOF (U = 398, P > 0.05)) of the pelvis, right side variables were used for further analyses. Descriptive statistics showed that females were larger than males in all pelvic measurements, except for WPU (Table 3). Considering the overall variables, MANOVA demonstrated significant difference between the sexes for pelvic bones (Wilks' lambda = 0.238, F = 10.05, P < 0.05). The range of SSD values was within 0.888 to 1.429 for most of the variables (LP, LP1, LP2, LPU, LOF, and WOF) (Table 3). Moreover, significant differences were detected between the males and females for three variables (LPU (U = 55.5, P < 0.05), WPU (U = 11.5, P < 0.05), and LOF (U =38.5, P < 0.05)).

Principal component analysis

In the principal component analysis of the external morphology, PC 1, PC 2, PC 3, and PC 4 explained 49.44%, 17.20%, 13.94%, and 10.47% of the total variation, respectively. PC 1 showed positive loadings for all variables (Table 4) and demonstrated high factor loadings (> 0.60) for HBL, TL, H, and E (Table 4). In PC 2, FF showed a relatively high positive loading and large positive loading was found for HF in PC 3 and for E in PC 4 (Table 4). Scatter plots based on the scores of the first and second (PC 1 and PC 2), first and third (PC 1 and PC 3), second and third (PC2 and PC3), and third and fourth (PC 3 and PC 4) components revealed that sexes partly overlapped with each other in all combinations (Fig. 4).

For the pelvis, the first four principal components explained 96.03% of the total variation. PC 1, PC 2, PC 3, and PC 4 explained 58.50%, 18.85%, 11.39%, and 7.29% of the variation, respectively (Table 5). High factor loadings (> 0.60) were seen for all variables, except two (WPU and WOF) in PC 1 (Table 5). In PC 2, WPU showed a relatively large positive loading. Large positive loadings were also found for WOF in PC 3 and for LOF in PC 4 (Table 5). Scatter plots based on the scores of first and second (PC 1 and PC 2) and second and third (PC2 and PC3) components showed a clear separation between the sexes (Fig. 5).

Discriminant analysis

Discriminant functions in the LDA of the log-transformed external morphological data showed the largest coefficient for HF (0.0100), followed by H (0.0065), HBL (0.0052), FF (0.0010), TL (-0.0002), and E (-0.0006) (Table 4). On axis 1, most male specimens (10/12) showed positive scores, while most female specimens (16/19) exhibited negative scores. Therefore, the scores of axis 1 revealed that 83.87% of individuals were classified into males or females (Fig. 6A). However, when the leave-one-out cross-validation approach (Jackknifing) was used to cross-validate the distinctiveness, only 64.52% of specimens were found to be correctly discriminated by the sexes using the external traits.

Table 2: Summary statistics of morphometric data (in mm) of the external morphology in *Bandicota bengalensis* (n: sample size; SD: standard deviation; SSD: sexual size dimorphism).

Variables	Males (n = 12)				Females (n = 19)				SSD
	Mean	SD	Min	Max	Mean	SD	Min	Max	
HBL	176.17	8.91	163.0	192.0	172.47	10.57	157.0	190.0	1.021
TL	145.58	5.35	138.0	154.0	145.95	10.29	126.0	169.0	0.997
HF	32.68	1.02	31.10	34.20	31.34	0.96	29.50	33.40	1.043
FF	18.30	1.08	16.60	20.10	18.22	0.99	16.30	20.40	1.004
H	50.33	2.24	47.20	53.50	48.99	2.56	42.50	53.80	1.027
E	21.76	0.97	20.00	22.90	21.81	0.80	20.50	23.40	0.998

Table 3: Summary statistics of morphometric data (in mm) of the pelvis in *Bandicota bengalensis* (n: sample size; SD: standard deviation; SSD: sexual size dimorphism).

Variables	Males (n = 11)				Females (n = 19)				SSD
	Mean	SD	Min	Max	Mean	SD	Min	Max	
LP	37.82	2.86	31.4	40.5	39.13	2.09	35.8	43.4	0.967
LP1	24.99	1.86	20.2	26.5	25.36	1.34	23.0	28.0	0.985
LP2	11.74	1.11	9.6	13.0	11.96	1.1	9.8	14.1	0.982
LPU	14.55	1.09	12.7	15.8	15.53	0.98	13.8	17.4	0.937
WPU	1.8	0.3	1.4	2.4	1.26	0.2	1.0	1.7	1.429
LOF	9.39	0.72	8.0	10.1	10.58	1.56	9.3	16.3	0.888
WOF	3.97	0.41	3.4	4.6	4.04	0.27	3.6	4.7	0.983

Table 4: Factor loadings for principal component analysis of *Bandicota bengalensis* based on correlation matrix of log-transformed external morphometric traits (PC 1, PC 2, PC 3, and PC 4) and first discriminant coefficient (axis 1) (High factor loadings (> 0.06) are shown in bold).

Variables	PC 1	PC 2	PC 3	PC 4	Axis 1
HBL	**0.782**	-0.339	-0.317	0.026	0.0052
TL	**0.853**	0.034	-0.196	-0.291	-0.0002
HF	0.506	-0.189	**0.833**	-0.050	0.0100
FF	0.416	**0.845**	0.054	-0.270	0.0010
H	**0.873**	-0.260	-0.038	-0.093	0.0065
E	**0.659**	0.314	0.005	**0.678**	-0.0006
Eigenvalues	2.966	1.032	0.836	0.628	-
Variance (%)	49.44	17.20	13.94	10.47	-

Table 5: Factor loadings for principal component analysis of *Bandicota bengalensis* based on correlation matrix of log-transformed pelvis variables (PC 1, PC 2, PC 3, and PC 4) and first discriminant coefficient (axis 1) (High factor loading (> 0.06) are shown in bold).

Variables	PC 1	PC 2	PC 3	PC 4	Axis 1
LP	**0.970**	0.098	-0.118	-0.106	0.0043
LP1	**0.914**	0.284	-0.011	-0.082	0.0020
LP2	**0.934**	0.152	0.030	-0.117	0.0024
LPU	**0.911**	-0.105	-0.263	-0.087	0.0080
WPU	0.061	**0.885**	0.368	0.256	-0.0434
LOF	**0.668**	-0.408	-0.009	**0.621**	0.0138
WOF	0.409	-0.445	**0.780**	-0.156	0.0023
Eigenvalues	4.094	1.272	0.828	0.515	-
Variance (%)	58.48	18.18	11.83	7.36	-

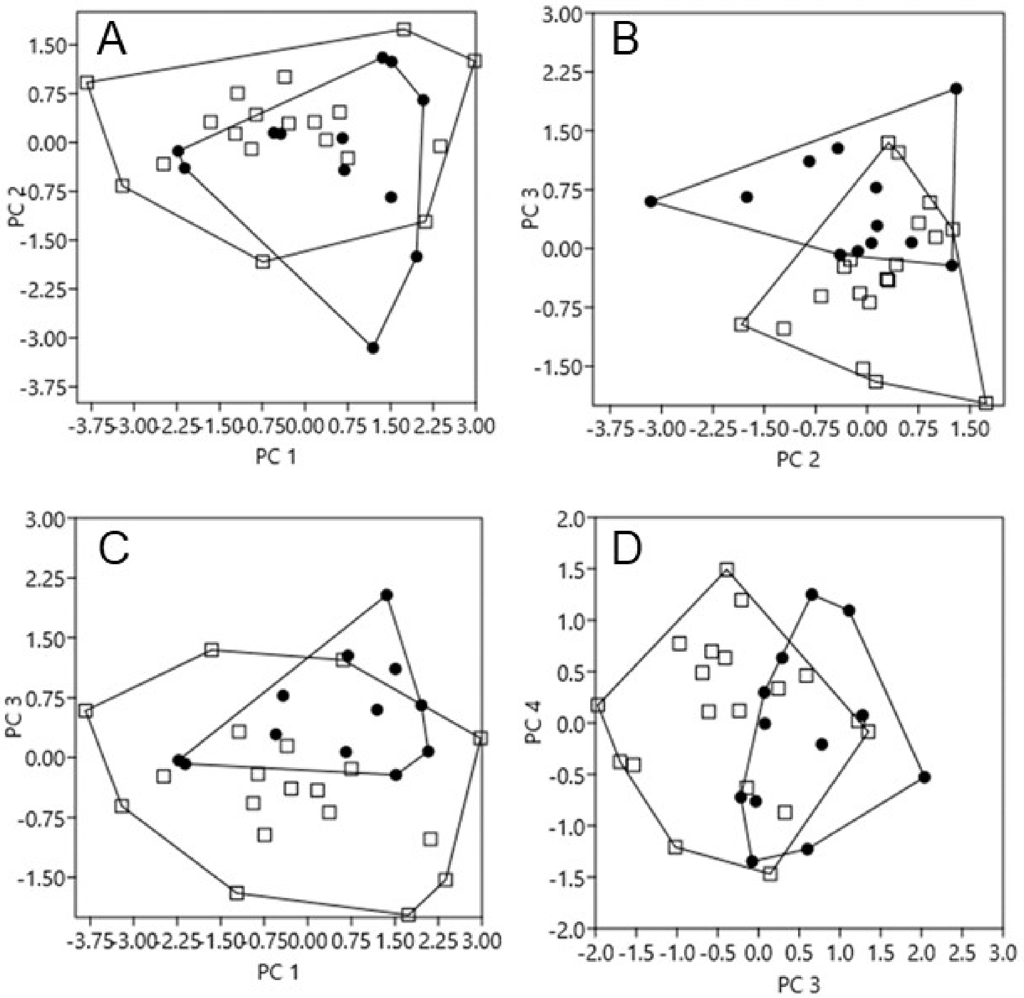

Figure 4: Plots of the scores of PC 1 and PC 2 (A), PC 2 and PC 3 (B), PC 1 and PC 3 (C), and PC 3 and PC 4 (D) for the external morphological traits of *Bandicota bengalensis*. Males and females are indicated by solid and open circles, respectively.

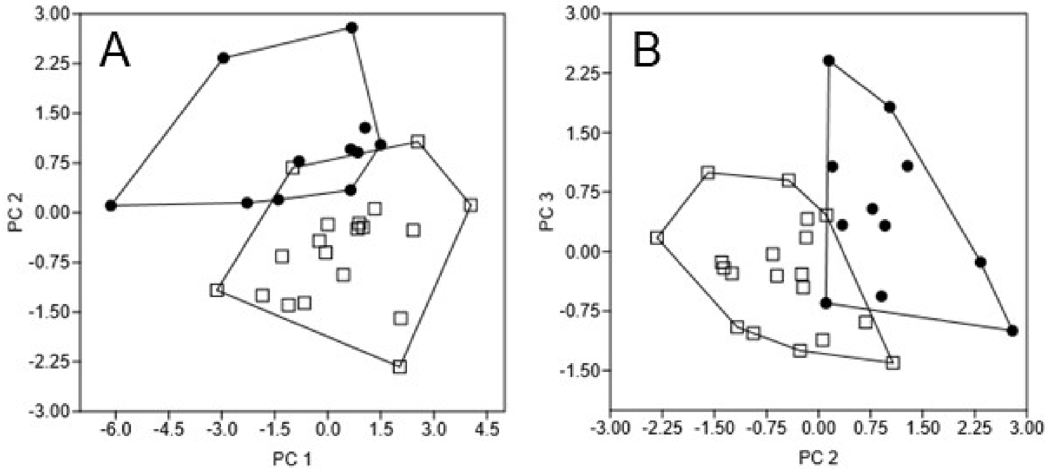

Figure 5: Plots of the scores of PC 1 and PC 2 (A), and PC 2 and PC 3 (B) for the pelvic measurements of *Bandicota bengalensis*. Males and females are indicated by solid and open circles, respectively.

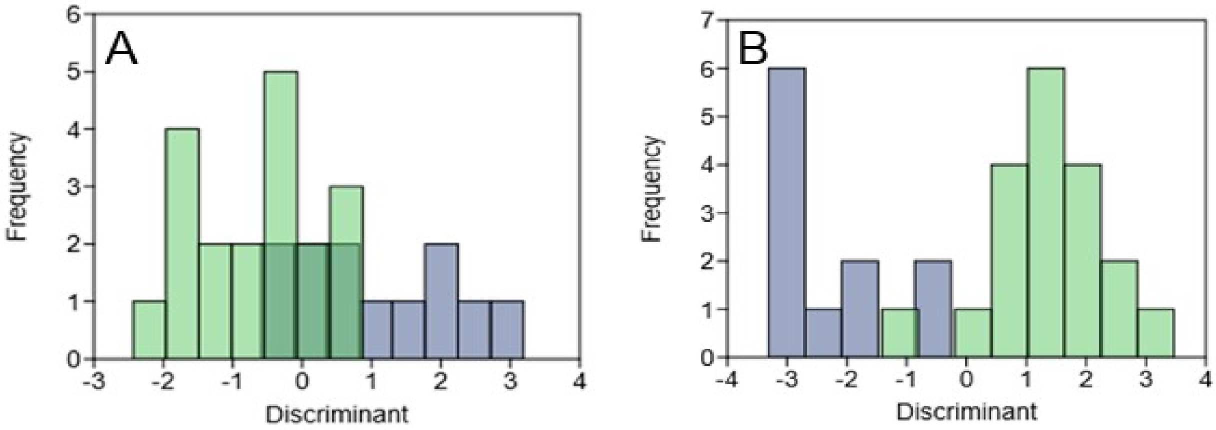

Figure 6: Linear discriminant function in the external morphology (A) and pelvis (B) of *Bandicota bengalensis*. Male and female specimens are represented by light blue and light green bars, respectively.

For the pelvis, the discriminant functions showed the largest coefficient for LOF (0.0138), followed by LPU (0.0080), LP (0.0043), and LP2 (0.0024) (Table 5). Along axis 1, most male specimens (10/11) showed negative scores, while most female specimens (18/19) exhibited positive scores. Therefore, the scores of axis 1 showed that 93.33% of individuals were classified into each sex (Fig. 6B). However, Jackknifed data showed slightly lowered (90 %) the proportion of correctly classified specimens by the sexes using pelvic measurements.

One-way ANCOVA: Comparison between the sexes

As three external variables (TL, H, and E) showed significant correlation with HBL in combined data, they were considered for this analysis. One-way ANCOVA indicated no significant differences in the slopes and adjusted means in the external morphology between the sexes (Table 6). In addition, four pelvic variables (LP1, LP2, LPU, LOF) showed significant correlation with LP and these were considered for one-way ANCOVA. Although slopes did not differ significantly between the sexes, the adjusted means of LP1, LPU, and LOF were found to differ significantly between males and females of *B. bengalensis* (Table 6; Fig. 7). However, the sexes almost completely overlapped in the plot of LP1 against LP (Fig. 7A).

Discussion

Our findings indicated that males were larger than females for most of the studied external morphological traits of *B. bengalensis*. MANOVA revealed significant differences in the external traits between the sexes. One-way ANCOVA showed that there was no significant difference between the sexes for the slope and adjusted mean values. Therefore, sexual dimorphism is mostly size related for external traits in *B. bengalensis* (Biswas et al., 2000).

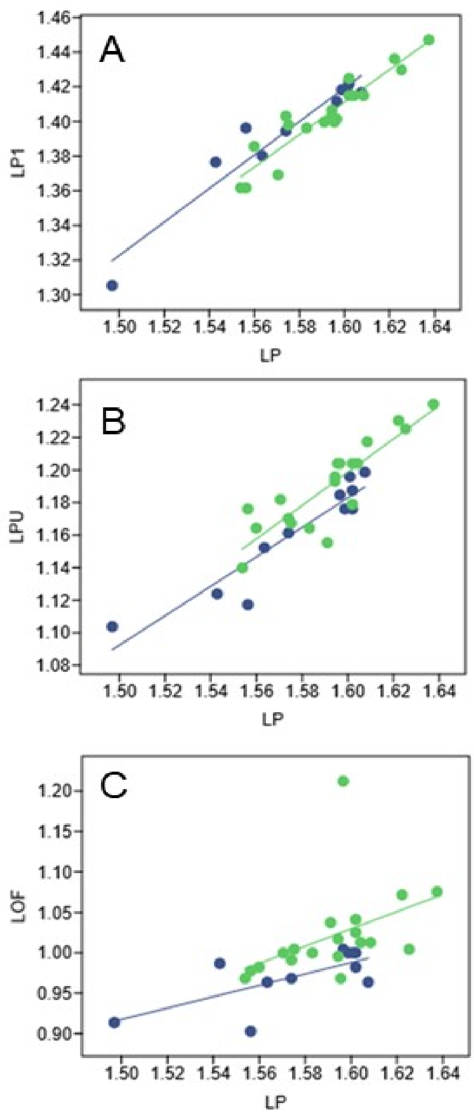

Figure 7: Plots of LP versus length of ilium (A), pubis (B), and obturator foramen (C) in *Bandicota bengalensis*. Male and female specimens are represented by light blue and light green circles, respectively.

Table 6: Adjusted means and slopes of external morphology and pelvis variables between the sexes of *Bandicota bengalensis*; based on analysis of covariance (one-way ANCOVA) (M: male; F: female; Diff: difference; n.s.: non-significant).

	Variables	Adjusted Mean		*F*	Diff	Slope		*F*	Diff
		M	F			M	F		
External Morphology	TL	2.16	2.17	0.730	n.s.	0.48	0.74	0.571	n.s.
	H	1.70	1.69	1.054	n.s.	0.63	0.57	0.057	n.s.
	E	1.34	1.34	0.382	n.s.	0.28	0.25	2.88E-06	n.s.
Pelvis	LP1	1.41	1.39	5.113	$P < 0.05$	0.97	0.94	0.061	n.s.
	LP2	1.08	1.07	3.262	n.s.	1.21	1.50	1.568	n.s.
	LPU	1.17	1.19	7.438	$P < 0.05$	0.91	1.02	0.427	n.s.
	LOF	0.98	1.02	4.495	$P < 0.05$	0.70	1.07	0.367	n.s.

Previous works found that males are usually heavier than females in most mammals (Kaur and Gurava, 1983; Rao et al., 2019). Sexual dimorphism in mammals is thought to evolve to ensure better reproductive success, usually in males (Shine, 1989; Nandini, 2011; McPherson and Chenoweth, 2012). Moreover, male–male competition for territory or resources was evoked to explain the evolution of male-biased sexual dimorphism, which is ultimately associated with male reproductive success (Anderson, 1994; Nandini, 2011).

A previous study reported that dominant males of *B. bengalensis* mostly take part in sexual activity (Parrack and Thomas, 1970). *B. bengalensis* is notoriously intolerant and male–male aggression has been reported (Sridhara, 1986). Therefore, male-biased sexual dimorphism in *B. bengalensis* may have evolved due to greater selection pressures on males (McPherson and Chenoweth, 2012), as males are dominant and exhibit more social interactions than females (Parrack and Thomas, 1970; Khairuddin et al., 2011; Rao et al., 2019). Moreover, females are less active and are observed gathering food in holes (Parrack and Thomas, 1970). Females with small body sizes could be able to reach small burrows, especially during pregnancy (Gliwicz, 1988; Wang, 2017).

Univariate analysis showed that the hind foot was significantly longer in males than in females of *B. bengalensis*. Discriminant analysis indicated that sexes could largely be differentiated using hind foot length. Principal component analysis showed high factor loadings for the fore and hind feet lengths in PC 2 and PC 3, respectively. Larger hind feet were also found in males of deer mice (Xia and Millar, 1986). The distal limb elements are more biomechanically important for half-bounding locomotion than proximal elements (Lamers et al., 2001). Therefore, sex differences in distal limbs are expected due to the difference in perspectives of locomotory strategies (Lamers et al., 2001). Previous studies reported that there is an association between hind foot length and mobility (Dice, 1940; Baker, 1968; Smartt and Lemen, 1980; Xia and Millar, 1986). Males normally possess a larger home range than females and show greater mobility and more aggressive behavior (Fulk et al., 1981, Sridhara, 1986). These phenomena might indicate the necessity of larger hind feet in males for greater mobility to maintain a relatively larger home range (Fulk et al., 1981, Sridhara, 1986).

On the other hand, female-biased sexual dimorphism was observed for the pelvis in *B. bengalensis*. Our results showed that the length of the pelvis, pubis, and obturator foramen was larger in females and the width of the pubis was smaller in females than in males. The Mann–Whitney *U* test showed a significant difference in the pubis length, pubis width, and obturator foramen length between the sexes. Moreover, one-way ANCOVA also demonstrated significant differences in the adjusted means of LP1, LPU, and LOF between the males and females. These indicate a relatively longer and thinner pubis in females than in males, which strongly supports previous findings in the bank vole (*Clethrionomys glareolus* (Schreber)) (Matysiak et al., 2017) and striped field mouse (*Apodemus agrarius* (Pallas)) (Balciauskiene and Balciauskas, 2016). It has long been known that the pelvic regions of certain mammals exhibit intraspecific structural diversity; however, the difference in single pelvis bones was not characterized and linked to sexual dimorphism until 1936 (Gardner, 1936). Pelvic sexual dimorphism has also been observed in *Apodemus* Kaup and *Mus* Clerck (Gardner, 1936; Dunmire, 1955).

Principal component analysis showed a clear separation in the form of the pelvis between males and females. The discriminant analysis also implied great distinctiveness between the sexes for pelvic morphology. The structural differences in the pelvis between males and females might be the consequences of hormonal changes, particularly of estrogen, throughout puberty (Gardner, 1936; Uesugi et al., 1992; Iguchi et al., 1995; Berdnikovs et al., 2007; Matysiak et al., 2017). The pelvis of females can be larger than males for reproduction purposes, as the pelvic girdle plays a role in pregnancy and childbirth (Matysiak et al., 2017). The birth canal needs to be enlarged during the pregnancy period of mammalian species. Therefore, the pubic bones of females could be elongated and thinner because the pubis typically makes up a major portion of the birth canal (Leute-negger, 1974; Ridley, 1995; Matysiak et al., 2017).

Conclusions

This study suggests that *B. bengalensis* is male-biased in secondary sexual dimorphism for the external morphology and female-biased for pelvis. These indicate differential patterns of secondary sexual dimorphism in the external morphology and pelvis of *B. bengalensis*, which may be associated with sexual selection and reproductive aspects, respectively.

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Author contributions

P.R., A.D., and J.K.B. conceived and designed the study, analyzed the data, and wrote the manuscript. P.R., A.D., and M.A.U. collected the specimens and carried out the morphological measurements. P.R., A.D., M.A.U., and J.K.B. reviewed the final article.

Conflict of interest

The authors declare that there is no conflicting issue related to this research article.

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