



Original investigation

Testing and quantification of cranial shape and size variation within *Meriones hurrianae* (Rodentia: Gerbillinae): A geometric morphometric approach

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ARTICLE INFO

Article history:

Received 5 November 2016

Accepted 22 August 2017

Handled by Vera Weisbecker

Keywords:

Jird

Mammals

Morphometrics

Muridae

Taxonomy

ABSTRACT

The Indian Jird, *Meriones hurrianae*, is unusual among the family Gerbillidae in not being from desert or sub-desert habitats, and in its ability to endure cold weather. Therefore, the distribution range of the Indian jird has no overlap with other species of *Meriones*. The habitat of the Indian jird is increasingly fragmented, so that this species is increasingly under threat. The ecology of this species, as well as its morphology, is poorly known. The present study, using a two-dimensional landmark-based geometric morphometric approach, aims to investigate intraspecific variation in skull shape and size of populations of this species. For this purpose, more than 50 skull specimens coming from different localities along the distribution range of this species were analyzed. The results allow us to reject the hypothesis that there would be no significant difference in skull shape and size. For instance, some specimens, such as those from Bandar Abbas (Iran), show significant shape differences compared with others. Differences were also significant for some size characteristics, e.g. cranium size and length, as well as the size of the auditory bulla. The observed morphological variation is discussed in the context of taxonomy and conservation of the Indian jirds.

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Introduction

Because of the complex taxonomy of rodents belonging to the genus *Meriones* (Darvish, 2011; Tabatabaei Yazdi et al., 2012), there is currently no in-depth study on their phenotypic variation in relation to species demarcation.

Meriones hurrianae Jerdon, 1867 is an Indian Desert Jird, also known as the Indian Desert Gerbil, distributed in India and Pakistan, extending westwards to Bandar Abbas, southeast of Iran, in similar climatic conditions (Musser and Carleton, 2005; Chakraborty et al., 2008; Tabatabaei Yazdi, 2011). Although knowledge about most ecological aspects of *Meriones* species in Iran and in the Middle East is still incomplete, it seems that winter temperature is an important factor in the distribution of the Indian Jird and the distribution range of this species, as this species is clearly limited in the north by winter temperatures (Misonne, 1959). The Indian Jird is diurnal in feeding activity; i.e. it is most active in the early morning and late afternoon. In contrast to other species of Gerbillidae such as *M. crassus*, *M. libycus*, and *M. meridianus*, this creature is not truly desertic or even sub-desertic, avoids rocky areas (in contrast of *M.*

persicus) and prefers habitats with acacia tree. Thus, as expected, the distribution range of the Indian Jird has no overlap with that of other *Meriones* species.

Morphologically, the Indian jird can be separated from other jirds by its relatively shorter ears, yellowish-grey belly fur, and comparatively short coarse greyish-buff dorsal fur. The claws tend to be dark brown and are noticeably long. The tail in this species is generally slightly shorter than the head and body length and terminated in a pencil tuft. Its fur is quite short and not soft or long, as the body fur of *M. persicus* (Ellerman, 1948; Darvish, 2011). *Meriones hurrianae* evolved some other characters such as a non-hypertrophied auditory bulla and naked hind foot (Chaworth-Musters and Ellerman, 1947; Pavlinov, 2008; Darvish, 2011), in common with its other co-habitants, e.g. *Tateraindica*, *Rhombomys* and *Gerbillus nanus*, potentially because of their similar ecology and environmental condition.

There is a strong link between adaptations towards visual and auditory acuity and predator/prey relationships in deserts. In a very dry atmosphere, the sensitivity to vibrations and ability to detect movement are perhaps more important than olfactory receptors (Tabatabaei Yazdi et al., 2014). Thus, in the Indian jird, it is not a disadvantage to have less inflated bullae in comparison with other jird species, such as *M. crassus*, *M. libycus*, and *M. meridianus*. In con-

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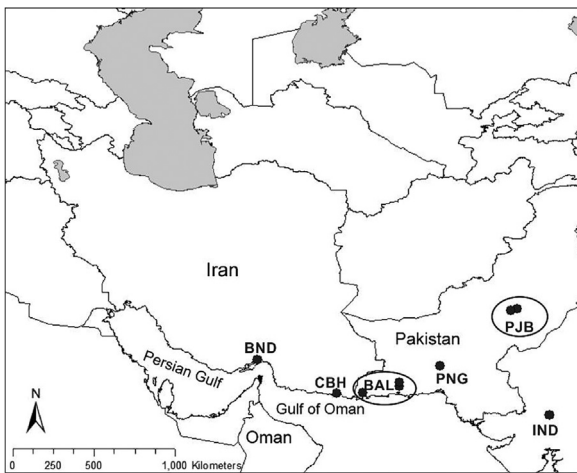


Fig. 1. Map showing the sampling localities. Ovals show grouped sampling localities grouped on the basis of geoclimatical closeness. For the description of localities abbreviations see Table 1.

trast, since they have a diurnal activity and live in dense colonies in a humid climate, a less inflated bulla in the Indian jird can be easily interpreted in this context. Having longer claws in these animals is an advantage and act as an adaptive value related to feeding behavior of the Indian Jird, as it enables them to burrow in sand dune areas of the seacoast, where they are found (Misonne, 1975; Ellerman, 1947; Lay, 1967; Roberts, 1999).

The patterns of morphological variation in many animal species are undoubtedly linked to environmental and habitat conditions, with population isolation driving the evolution of phenotypic diversity (Milošević-Zlatanović et al., 2016). Considering the Indian jird living in habitats with different geoclimatic conditions, such as rainfall, we tested the link with craniomorphological plasticity in this species. We also focus on the patchy distribution of the populations because of habitat fragmentation during the last decades. Using a geometric morphometric approach (Zelditch et al., 2004), we first tested whether geographical distribution of the Indian jird specimens reflect a pattern of cranial variation and how morphological traits vary across their distribution range. Then, it was evaluated to see to what degree the local populations of Iran can show cranial shape and size differences. Finally, the morphological differences are discussed in the context of taxonomy and biological conservation.

Material and methods

A total of 52 skull specimens from 10 localities, originating from northwest India to the south of Iran, were analyzed (Table 1, Fig. 1). Since the ventral side of two specimens from India was broken, they were not included in the analyses of the ventral side. The specimens were obtained from the collections of the Smithsonian Natural Museum of Natural History (Washington D.C. USA), the Field Museum of Natural History (Chicago, USA), the Natural History museum of the British museum (London, UK), and the Muséum National d' Histoire Naturelle (Paris, France). A list of examined specimens with catalog number is available in Appendix A.

The specimens were identified based on the identification keys using all external and cranial data available by following the keys to jirds (Chaworth-Muster and Ellerman, 1947; Darvish, 2011). The juvenile specimens were identified (Petter, 1959; Pavlinov, 2008) and excluded from the analyses based on the molars' eruption.

To apply a two-dimensional landmark-based geometric morphometric approach (Bookstein et al., 1985; Bookstein, 1991; Klingenberg et al., 2005; Klingenberg, 2009, 2010; Klingenberg and

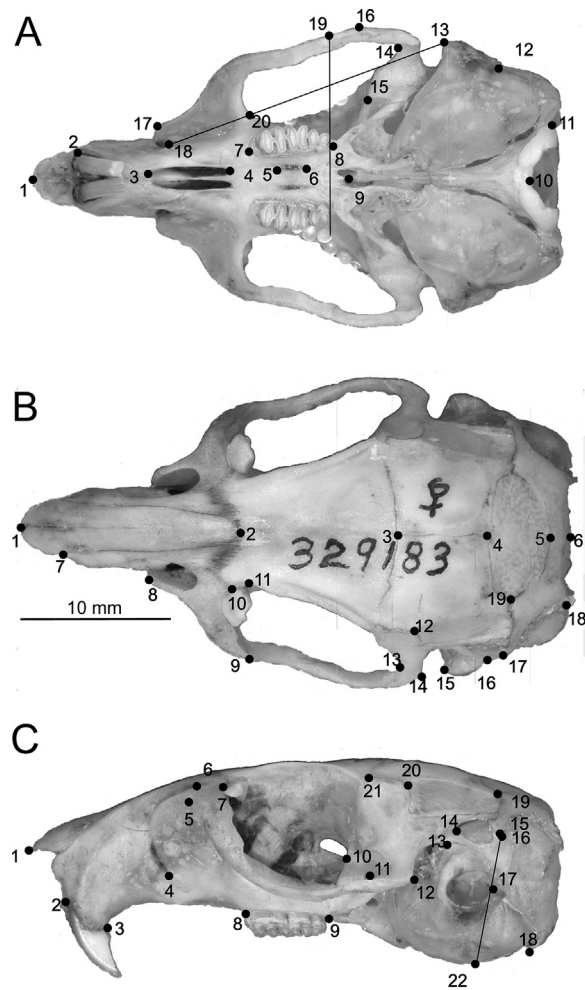


Fig. 2. Collected landmarks on the ventral (A), dorsal (D), and the Lateral (L) sides of the skulls. The landmarks are defined in Appendix B in the Supplementary material.

Gidaszewski, 2010; Cardini, 2012), the images of the ventral, dorsal, and lateral sides were digitized by a Nikon D70 digital camera by macro lens using a standardized protocol (Tabatabaei Yazdi, 2011; Tabatabaei Yazdi and Adriaens, 2011; Tabatabaei Yazdi et al., 2012; Tabatabaei Yazdi and Adriaens, 2013; Tabatabaei Yazdi et al., 2014). A scale was included in the images to allow the acquisition of a scaling factor for calculating centroid sizes in the metric system. Respectively, 20, 19, and 22 landmarks on the ventral, dorsal, and lateral sides were collected (Fig. 2) using the TpsDig program (Rohlf, 2013). The landmark positions were defined (Appendix B in the Supplementary material) based on the terminology used by Popesko et al. (2002). Before doing the shape analyses, the obtained landmark configurations were aligned by doing the generalized Procrustes analysis (GPA; Rohlf and Slice, 1990) using PAST ver. 3.14 (Palaeontologica Statistics, Hammer et al., 2001). GPA is a method that translates coordinate configurations to a common centroid by scaling them to unit centroid size and rotating them in order to minimize the sum of squared distances between the corresponding landmarks (Zelditch et al., 2004).

For each view, TpsSmall program was used to test the correlation between Procrustes shape distances and their corresponding Euclidean shape distances after projection in Euclidean shape space (Rohlf, 1998).

Size was computed as the centroid sizes (CS), which is the square root of the sum of the square of the distance between landmark and centroid (Bookstein, 1991; Rohlf, 1996). Size differences between the groups were investigated for the ventral, dorsal, and

Table 1
List of the analysed specimens. To perform robust canonical variate analyses, localities represented by only a few specimens were pooled according to their geographic proximity into six analytical groups i.e. CBH, BND, PLB, PNG, BAL, IND.

Country and Province	Precise locality	Lat.	Lon	Sample size	Abbreviation of the groups
Sistan and baluchestan, Iran	Chabahar	25.283 N	60.633 E	5	CBH
Hormozgan, Iran	Bandar Abbas	27.183 N	56.267 E	3	BND
Punjab, Pakistan	Dera Ghazi Khan	30.033 N	70.633 E	7	PJB
Punjab, Pakistan	Sakhi Sarwar	29.967 N	70.300 E	30	PJB
Balochistan, Pakistan	Panjgur	26.750 N	64.150 E	2	PNG
Balochistan, Pakistan	Bela	26.117 N	66.317 E	1	BAL
Balochistan, Pakistan	Dasht River	25.417 N	62.100 E	1	BAL
Balochistan, Pakistan	Wadh	27.333 N	66.350 E	1	BAL
Gujarat, India	Palanpur	24.167 N	72.417 E	2	IND

lateral sides, separately. In addition to CS, some other characters, which have shown intraspecific variation in some jird species and have been used as a diagnostic feature (Tabatabaei Yazdi et al., 2012), were also investigated: relative length of the incisive foramen (distance between landmarks 3 and 4, divided by CS, ventral side), relative length of the palatine foramen (distance between landmarks 5 and 6, divided by CS, ventral side), relative size of the distance between incisive foramen and tooth row (distance between landmarks 4 and 7, ventral side), cranium length (distance between landmarks 1 and 6, dorsal side), and the posterior opening of the suprêmeatal triangle (distance between landmarks 15 and 16, divided by CS, lateral side). The landmark distances were calculated in PAST and the relative lengths were calculated using Microsoft Office Excel 2007. Size variation was visualized by the bee swarm plots (Fig. 3), and the shape variation was demonstrated by the scatter plots of PC-scores (Figs. 4 and 5), using STATISTICA program (StatSoft, version 7.0, www.statsoft.com, StatSoft, Inc., Tulsa, USA).

First, a pairwise testing for sexual dimorphism was carried out by applying a Monte Carlo randomization on the pooled dataset (partial warp scores) of all three skull sides. Since this test showed no sexual dimorphism in the skull shape ($p > 0.5$), the specimens of both sexes of each OTU were pooled in the same group for further analyses. Still, sample size for some OTU's was relatively low compared to the number of variables. As such, we performed a randomization test (Hammer et al., 2001) to test morphological differences between the operational taxonomic units (OTU's) (Table 2). Accordingly, the pairwise testing was done with a Monte Carlo randomization with 10,000 permutations on the size and shape datasets, using the Poptools 3.2.3 for Microsoft Office Excel (Hood, 2010; Tabatabaei Yazdi et al., 2011).

The principal component analysis (PCA) and canonical variate analysis (CVA) were respectively performed on shape variables (partial warps) in STATISTICA, to demonstrate the morphological variation and group differences by relevant scatter plots. In CVA, the group of India (IND) with single specimen in the ventral side, is excluded. MorphoJ software (Klingenberg, 2010) was used to visualize the deformations by the outline drawings.

In order to evaluate the overall pattern of morphometric similarities among the OTU means, an unweighted pair group method with arithmetic mean (UPGMA) cluster analysis (Sneath and Sokal, 1973) was performed on the matrix of shape distances (Euclidean Distances) between the OTU means, using PAST (with 10,000 randomizations to show the branch supports). For doing UPGMA, the partial warp scores of the three views were pooled. The corresponding matrix of the Euclidean distances was calculated using the Poptools 3.2.3 add-on of Excel (Hood, 2010). To test correlation between size (log centroid size) and shape (partial warps) variables of three sides of the skulls, multiple linear regression analyses were performed in STATISTICA.

Some sample localities were pooled according to their geoclimatic proximity into larger operational groups (Fig. 1, Table 1),

because canonical variate analysis cannot be performed when the sample size per groups is too small in relation to the number of variables used (Kovarovic et al., 2011). With the absence of direct evidence of population boundaries (such as population genetic sub-structures), geoclimatical affinities are used as proxies.

Results

The correlation between Procrustes shape distances and their corresponding Euclidean shape distances for each view were one (1.0000). Thus, the projections were set to the orthogonal shapes.

Size

Significant size differences ($F_{\text{ventral}} = 3.524$, $P = 0.009$; $F_{\text{dorsal}} = 4.31$, $P = 0.003$; $F_{\text{lateral}} = 3.65$, $P = 0.007$) are found among the groups. Based on the three views, the Bandar Abbas and the Indian groups have the largest and smallest crania, respectively; though not significantly different from all others on the ventral side (Fig. 3, Table 2). The crania of the Bandar Abbas and the Indian specimens, respectively, are significantly bigger and smaller compared to that of the other groups, in both CS (dorsal and lateral sides) and cranial length (Lm 1-6, dorsal side).

Although the incisive and palatine foramina show some variations among the groups, their relative size to the CS are not significantly different (Table 2).

In the lateral side, the Punjab specimens have a considerably wider suprêmeatal triangle. In other words, these specimens show a larger distance between the lateral tip of the supraoccipital process and the tip of the hamular process of temporal bone, compared to the specimens of other groups, especially those from Bandar Abbas a with completely closed suprêmeatal triangle (Fig. 3, Table 2). The overview of the statistical pairwise comparisons between all groups is given in Table 2.

Shape

Multiple linear regression analyses show significant relationships between size and shape variables for all skull sides ($R^2 = 0.45$, $P \leq 0.001$), suggesting that a significant part of the observed shape variation between the groups is because of size dependent allometry.

The principal component analysis (PCA) results illustrate the shape variations. The shape variation within and among the groups, as well as the distribution of the specimens in the morphospace (PC1 vs. PC2), are shown in Fig. 4. Although the specimens of some groups overlap in morphospace, the Bandar Abbas group occupies a distinct position at the ventral and lateral skull shape.

With respect to the ventral shape, the first axis represents the major variation in the convexity of the zygomatic arch (Lms 16 and 19) and the inflation of the bulla (Lms 12 and 13). The second axis mainly represents the nasal length variation (Lm 1). Along PC1,

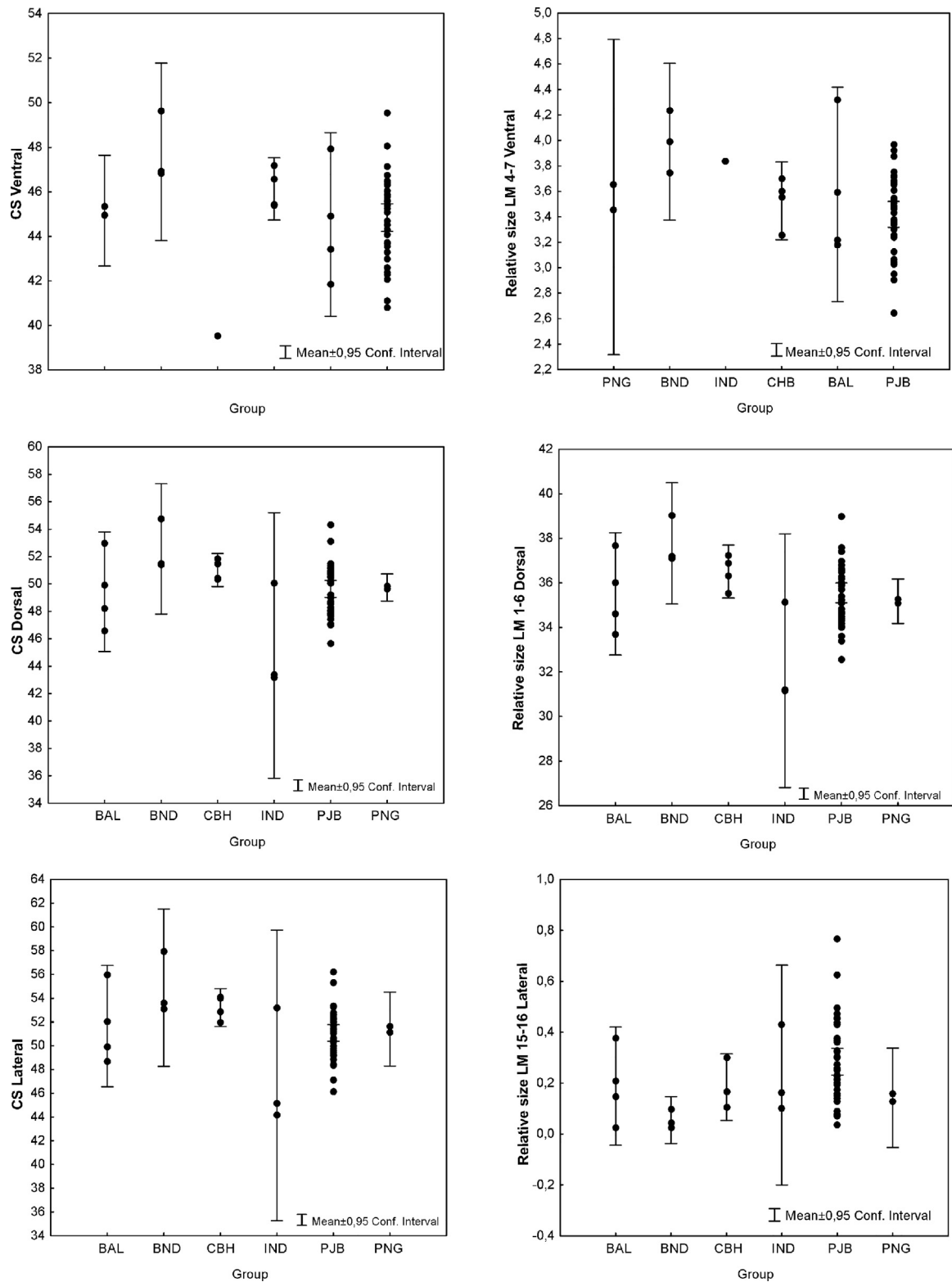


Fig. 3. Stripcharts of the size characters, Group1 = Baluchistan, Group2 = Bandar Abbas, Iran; Group3 = Chabahar, Iran; Group4 = Palanpur, India; Group5 = Punjab, Pakistan; Group6 = Panjgur, Pakistan.

specimens from Bandar Abbas with lower scores have relatively narrower zygomatic plates, less inflated bullae, and wider zygomatic arches. Along the second axis, the groups show a different degree of variation.

With respect to dorsal shape, the Bandar Abbas and Chabahar specimens (positive values of PC1) are characterized by a longer

rostrum and a restriction of the interparietal bone. The specimens from Pakistan and India overlap in some part of morphospace, except for those from Punjab. The later specimens occupy the intermediate position in morphospace. The first PC allows a partial discrimination between specimens from Iran and India. The second PC-axis represents a variation in the interparietal restriction.

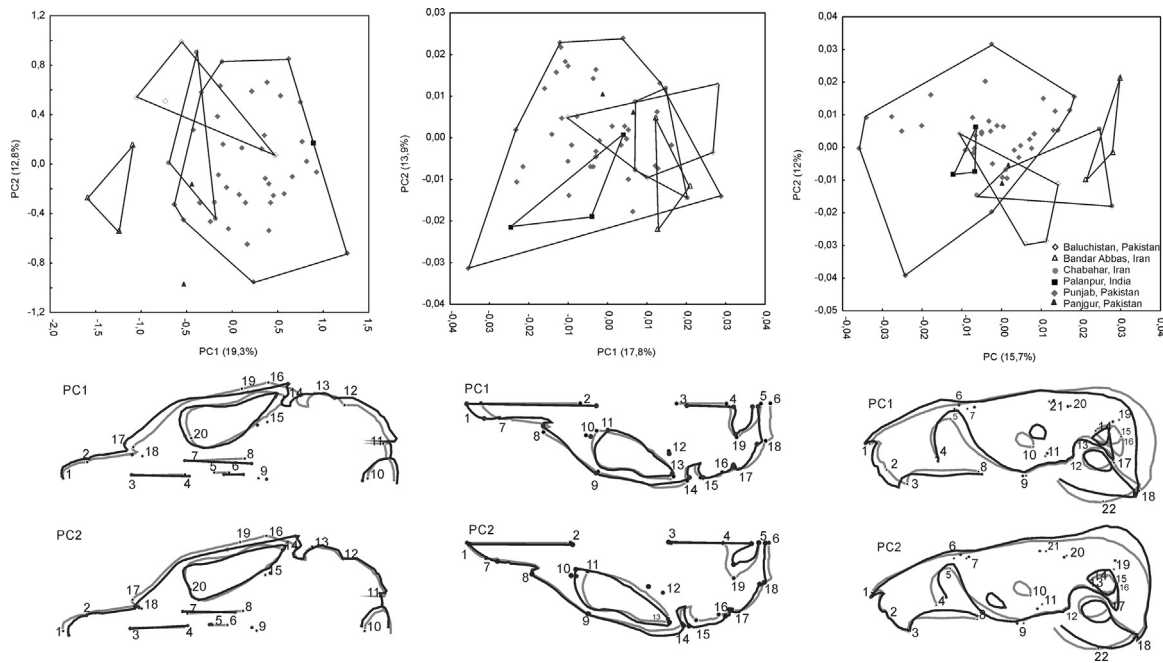


Fig. 4. PCA scatter plot using shape data of the ventral (A), dorsal (B), and lateral (C) side of the skull in the *Meriones hurrianae* groups. Deformed outline drawings show the shape changes from the overall mean (in gray) associated with each CV axis to the extreme (in black) in positive directions. The percentages of variances explained by the axes are shown in parentheses.

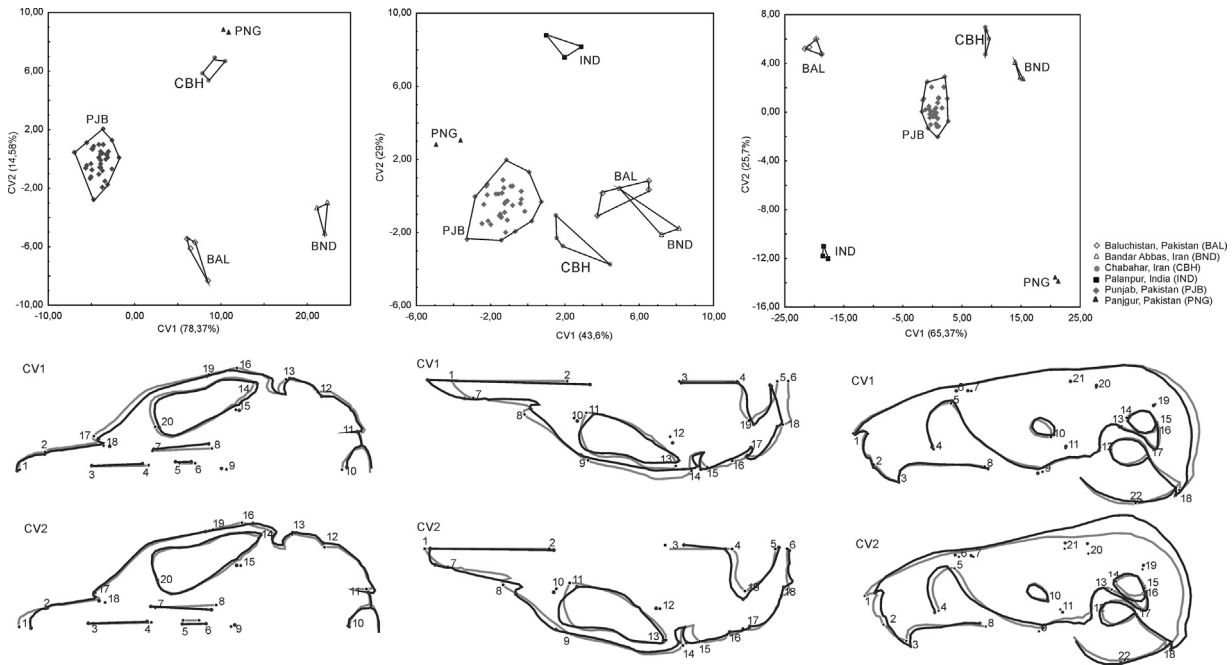


Fig. 5. CVA scatter plot using shape data of the ventral (A), dorsal (B) and lateral (C) side of the skull in the *Meriones hurrianae* groups. Deformed outline drawings show the shape changes from the overall mean (in gray) associated with each CV axis to the extreme (in black) in positive directions. The percentages of variances explained by the axes are shown in parentheses.

Along with this axis, the Punjab specimens occupied the main portion of the morphospace and the other groups specimens show an intermediate position in morphospace. With respect to the lateral shape, the Bandar Abbas and Chabahar specimens with the highest PC1 scores show a partial overlap in morphospace and are characterized by a restriction of the occipital bone. The second axis represents the major variation in the position of the optic canal and height of skull in the occipital part.

The CVA performed on the three views datasets shows a considerable discrimination of the Bandar Abbas group from the others, especially from the Palanpur, Punjab, and Panjgur (Fig. 5, Table 2). In the ventral and dorsal plots, the specimens from Bandar Abbas have higher and those from Punjab have lower CV1 scores. In addition, the specimens from Bandar Abbas show relatively wider zygomatic plates. In the ventral view (Fig. 5A), the specimens from Panjgur and Chabahar are characterized by shorter nasals. With respect to the CV1 axis in the dorsal shape (Fig. 5B), specimens of Punjab group are

Table 2

Pairwise group comparison and the level of differences between them. The p-levels were obtained from the Monte-Carlo randomization test (*p < 0.01, **p < 0.005 and ***p < 0.0001).

Pairwise groups	Size Ventral				Size Dorsal		Size Lateral		Shape		
	CS	LM(5–6)/CS	LM(3–4)/CS	LM(4–7)/CS	CS	LM(1–6)/CS	CS	LM(15–16)/CS	Ventral	Dorsal	Latral
Panjgur – Bandar Abbas	–	–	–	–	*	***	**	–	*	–	*
Panjgur – India	–	–	–	**	***	***	**	–	–	–	–
Panjgur – Chabahar	–	–	–	–	***	–	**	–	–	–	–
Panjgur – Baluchistan	–	–	–	–	–	–	–	–	*	–	–
Panjgur – Punjab	–	–	–	–	–	***	–	–	*	–	–
Bandar Abbas – India	***	–	–	*	***	***	***	–	***	–	**
Bandar Abbas – Chabahar	–	–	–	–	–	***	**	–	–	–	–
Bandar Abbas – Baluchistan	–	–	–	–	***	***	**	–	–	–	–
Bandar Abbas – Punjab	–	–	–	**	***	***	**	*	***	***	**
India – Chabahar	**	–	–	**	***	***	**	–	–	–	–
India – Baluchistan	–	–	–	–	***	***	**	–	–	–	–
India – Punjab	*	–	–	*	***	***	**	–	–	–	–
Chabahar – Baluchistan	–	–	–	–	***	***	**	–	–	–	–
Chabahar – Punjab	–	–	–	–	***	–	**	–	–	–	–
Baluchistan – Punjab	–	–	–	–	–	–	**	–	–	–	–

characterized by restricted occipital bones. The second CV represents variation in the interparietal restriction. Along with this axis, the Panjgur specimens are characterized in having a broader interparietal bone (Fig. 5B). In the lateral view, CV1 mainly represents occiput restriction. The specimens from Palanpur and Baluchistan have the lowest scores while specimens from Panjgur, Bandar Abbas, and Chabahar, on another extreme, have the highest score. With respect to CV2, the observed differences are mainly in the position of the infraorbital foramen on the zygomatic plate and occiput. In the plot of the lateral shape data, the specimens from Punjab are positioned in the mediate of the morphospace.

Generally, the Palanpur specimens are positioned slightly apart from the others along CV2 of all plots (Fig. 5A–C).

With respect to the Euclidian distances, the size differences were more distinct for the dorsal dataset than for the other configurations. However, for the shape, the ventral side shows more group distinctions (Table 2). The pairwise comparisons showed that the specimens from Bandar Abbas are significantly different from the other groups, especially those from Punjab. The differences were less distinct and not significant between the two Iranian groups, except for the relative length of the skull [dorsal side, ((LM 1–6)/CS)] that was significantly different in samples from Chabahar and Bandar Abbas (Table 2). However, most of the compared groups show such significant differences in the relative size of the skull, as well (Table 2).

The cluster analysis, based on the pooled dataset of all three skull views, corroborated the Monte-Carlo Randomisation results, yielding two main groups: (1) Bandar Abbas and Panjgur, and (2) Punjab, India, Chabahar, and Baluchistan (Fig. 6).

Although the specimens from Bandar Abbas are more distinct from those of other groups, they are clustered with the specimens from Panjgur. Moreover, the Chabahar and Bandar Abbas groups, which do not show a significant shape difference (based on the results obtained from Monte-Carlo Randomisation tests) are not clustered together in the dendrogram.

Discussion

Morphological variation

The results suggest that previous taxonomic work on *Meriones* was too restricted, at least, in the terms of taxonomy and ecomorphology. Most of the keys and revisions of *Meriones* species have focused on external diagnostic features rather than the cranial characters, with subspecies diagnostics generally not being unambiguous (Chaworth-Musters and Ellerman, 1947). In addition, most

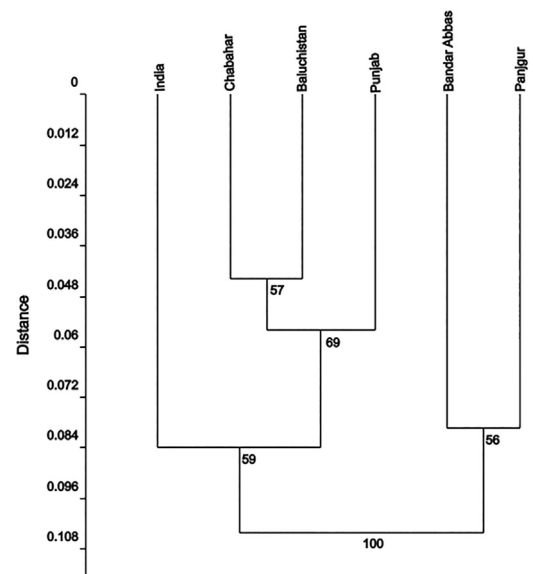


Fig. 6. Dendrogram obtained from the UPGMA, using Euclidean distances between group means by combining all data (shape information from ventral, dorsal, and lateral view). Branch bootstrap support is shown at the nodes for 10,000 replicates.

of these studies have been conducted using few local samples or specimens covering a limited distribution. For instance, the studies conducted by Roberts (1997), and Osborne and Helmy (1980) do not cover the distribution range of these species. For instance, based upon the keys on Jirds [Chaworth-Musters and Ellerman (1947), updated and modified by Pavlinov et al. (1990) and Darvish (2011)], the suprimeatal triangle in *Meriones hurrianae* should be completely closed posteriorly and the lateral tip of supraoccipital process should reach the tip of the hamular process of the temporal on the suprimeatal triangle (landmarks 15–16, lateral view). However, the present study shows that the suprimeatal triangles are not closed posteriorly in some specimens, for example those from Punjab, Pakistan. In addition to the phenotypical differences between the *M. hurrianae* populations, my findings confirm the existence of extensive morphological variability in jirds, which was also suggested in the past by Chevret and Dobigny (2005) and Colangelo et al. (2010). The results also clearly demonstrate the existence of morphological variability at the level of the suprimeatal triangle, interparietal, zygomatic arch, and the nasal in this species. Such an intraspecific variation has already been observed in other jird

species; e.g. *M. crassus* and *M. meridianus* (Tabatabaei Yazdi et al., 2011; Tabatabaei Yazdi 2011).

In agreement with the observations on the external characters, the cranial differences observed in this study clearly support the hypothesis that specimens of Iran, especially those from Bandar Abbas as the western geographical forms of *M. hurrianae* (Misonne, 1959; Darvish, 2009, 2011), are indeed phenotypically distinct from those from other parts of its distribution range; i.e., India and Pakistan.

The amount and patterns of the morphological variations help provide criteria for discrimination of OTU'S within the Indian jird. Although most of the observed morphological variation could directly be used by taxonomists, some characters need to be translated into linear measurements to become more usable in the frame of an identification key for the taxonomists.

Although for all groups, except for the Punjab group, we had relatively small sample sizes, investigations on size and shape variables could show substantial differences between the OTU'S. Actually, the results have demonstrated considerable morphological variation among the Indian jird' specimens originate from throughout the distribution range of this species. Among the studied specimens, those from Bandar Abbas are morphologically highly unusual and therefore, might be considered a separate subspecies. However, larger samples sizes are required to confirm this. Also, a phylogeographic investigation on the population structure of the Indian jird may show the relationship of this population with other populations, especially with the population from Chabahar, Iran. Hence, the species and subspecies recognition remain ambiguous and thus hypothetical. In fact, this claim is extendable to other *Meriones* species occurring in the Middle East, such as *M. meridianus* (Tabatabaei Yazdi et al., 2012) and for most rodent species of this region.

Biodiversity and conservation

Although the Indian Jird is listed as “Least concern” (LC) with the International Union for Conservation of Nature Red List (IUCN, ver. 3.1), its habitats are increasingly impacted by climate change (Harley, 2011), degradation, and habitat loss caused by the expansion of civilization and unsustainable agriculture. The socio-economic changes in the habitats of this species have led to ecosystem destruction and fragmentation that prevent the formation of a climatic climax community within the surviving habitat islands (Thomas et al., 2001). This points to a need for both species-specific and biotope specific conservation approaches in the distribution range and potential habitats of the Indian jird.

Based on the personal observation of the author and the unpublished reports of rangers, the Indian jird is currently extinct from some parts of its distribution range, e.g. from south of Iran. But, the IUCN status of the population trend of *M. hurrianae* is unknown (IUCN, 2015) and the threats to this species are intensified (Chakraborty et al., 2008). Thus, the focus of the conservation plans on the remaining populations of this species should be increased and consequently, changing the status of the Indian jird to “threatened” is recommended. Otherwise, as the main part of this species' population in the south of Iran (where the studied samples are originated from, e.g. Chabahar) has been locally extinct (personal observation of the author and the unpublished reports of rangers), the Indian jird is at least facing an extirpation at the country level and would be totally removed from the fauna of Iran shortly. In other words, we are facing a local extinction for the Indian jird!

Given the morphological diversity across the distribution of *M. hurrianae*, it is possible that this species consists of several subspecies or even species. Distinguishing multiple species within a nominal species has already been conducted in many animal species and cryptic species have been found frequently. For exam-

ple, three new species have been recognized within the Asian Arowana (*Scleropages formosus*) by Pouyaud et al. (2003). As this species was considered an endangered species, the existence of multiple species within it could clearly demonstrate the need for a reconsideration of their conservation status (Pouyaud et al., 2003). In addition, considerable studies on evolutionary diversification and speciation in rodents have already been conducted, resulting in distinguishing some cryptic species. For example, a phylogenetic study on the *Peromyscus melanophrys* species group by Castañeda-Rico et al. (2014) presented a new phylogenetic relationship within these taxa and demonstrate distinct clades within the studied species. Therefore, similar to this case, the Indian jird might be cryptic species facing the risk of extinction, due to isolation of populations and restricted habitats.

Due to the low population size of the Indian jird in the south and south east of Iran (with unknown population size and viability trends) and the huge habitat degradation occurred during the last decade in their distribution range (Chakraborty et al., 2008), a study must be conducted on the actual habitats of this species. For this purpose, an intensive trapping in the sampling localities of the museum's specimens must be done for estimating the abundance of this species in their current habitats. Moreover, further studies on the taxonomy of the Indian jird, as conducted on the Persian jird by Dianat et al. (2017), are required to clarify the phylogenetic relationship within this species and determine genetic diversity within the populations.

Acknowledgements

I am very grateful to the museum curators, who provided me with access to the collections. Thanks to anonymous referees of the earlier drafts of this manuscript and Prof. Dominique Adriaens for their valuable comments. I am thankful for my student Mrs. Faegheh Majdi, because of her assistance in picture landmarking. This work is partly financed by Ferdowsi university of Mashhad, Iran (project number 32600).

Appendix A. List of the analyzed specimens

Smithsonian Natural Museum of Natural History (Washington D.C. USA): 328339, 329183, 353682, 353683, 369161, 369162, 369163, 369164, 369165, 369166, 369510, 369518, 369519, 411108, 411110, 411111, 411113, 411115, 411116, 411117, 411118, 411119, 411120, 411121, 411122, 411124, 411126, 411127, 411128, 411129, 411130, 411131, 411132, 411134, 411135, 411136, 411137, 411138, 411139, 411140, 411141, 411142.

Field Museum of Natural History (Chicago, USA): 83071

British Museum of Natural History (London, UK): 1911854, 74112118, 1911849, 1911851, 1911853, 763101.

Musée National d'Histoire Naturelle (Paris, France): 1328, 1329.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.mambio.2017.08.004>.

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