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Original investigation

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

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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.

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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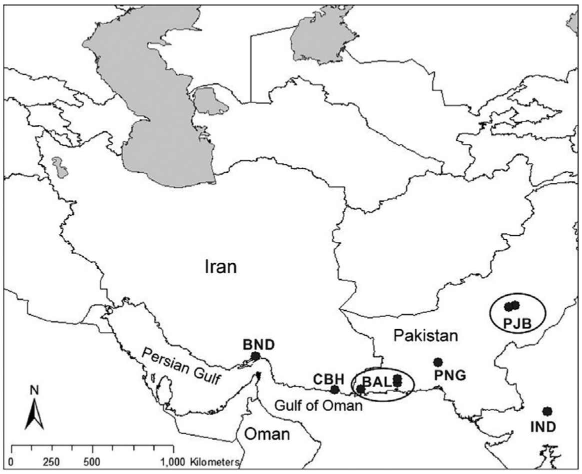

Fig. 1. Map showing the sampling localities. Ovals show grouped sampling localities grouped on the basis of geoclimatical closeness. For the description of localities abbreviations see Table 1.

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 theBritish 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

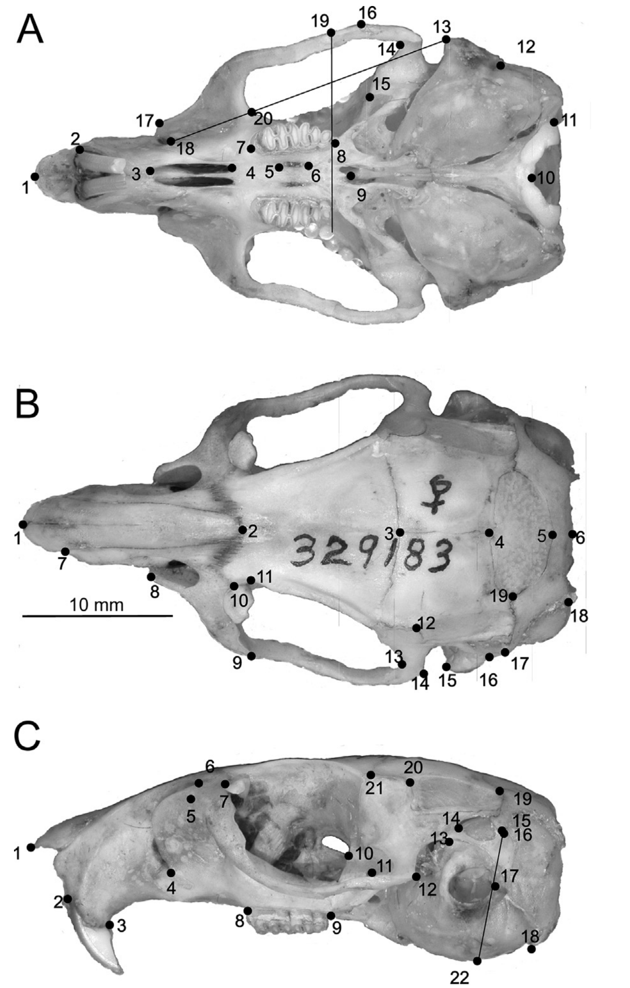

Fig. 2. Collected landmarks on the ventral (A), dorsal (D), and the Lateral (L) sides of the skulls. The landmarks are defined in Appendix B in the Supplementary material.

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