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Full Length Article

Sexual dimorphism of Cranial shape in Iranian Brown Bear *Ursus arctos* Linnaeus, 1758 using Geometric Morphometric approach

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ABSTRACT
The Iranian brown bear is distributed in north, west and northwest of Iran. This research was conducted to study the sexual dimorphism of Iranian brown bear in Alborz and Caucasia population using Geometric Morphometric. Sixty two skulls were studied based on species distribution in country. There was a significant difference between male and female's skull shape confirming the presence of sexual dimorphism in the skull shape of Iranian brown bear. Comparison of shape of two sexes showed the reinforcement and strength different parts in males' skull. Dimorphism can also be related to the social ecology of brown bears.
Key words: *Brown bear, Sexual dimorphism, Geometric Morphometric, Skull.*

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INTRODUCTION

The Iranian brown bear *Ursus arctos* is found broadly in the northern, western and northwest of the country associating with the Alborz, Zagros and Caucasia Mountains [11, 17, 24, 39]. These populations are being fragmented and roughly estimated 1700-2000 [13] for the whole country protecting by law and listed in "Protected" category [7, 8].

Cranium characteristics is applicable for studying phenotypic variation, as it is both genetically and functionally relevant and subjected to a substantial amount of selective pressure [3, 6, 36]. The sexual dimorphism in cranial shape is also common phenomena among mammals and present in species with a polygynous social ecology reflecting increased male-male competition [4]. But there is no information about the sexual dimorphism in the cranial shape of Iranian brown bear.

Geometric morphometric (GM) is a quantitative method to analysis shape and widely applied to compare shape variations of biological structures [34]. Unlike traditional approach, in GM, data is obtained from the coordinates of landmark points [1], which are morphological points of specimens that are biological interest [30].

This research was conducted to study of the sexual dimorphism using the visualization techniques afforded by GM approach based on the Alborz and Caucasia populations.

MATERIALS AND METHODS

Study area and sample collection: The Northern forests of Iran from Astara in the northwest to the eastern Golestan Province support a larger population of brown bear [11, 16, and 24]. Since various ecosystems can be found in this region, from Irano-Turanian landscapes in the south to highland alpine with altitude to 5600 m scrublands extending to deep hyrcanian forests adjust to the Caspian Sea. These forests are heavily covered by snow from December until March and are not accessible over that period. Therefore, it expected finding more samples in Alborz regions than Caucasia [24]. Iran's Caucasia Mountain in the northwest of country is a part of the Lesser Caucasus system and contained the Azarbaijan and Ardabil Provinces. The Zagros Mountains from south of Azerbaijan area to near Shiraz in the Fars Province, are in west with highest point about 4200 m is the largest mountain range in Iran. (Fig. 1). The distribution of bear in two latter regions has been reported to be sporadic [16].

Fig. 1: Distribution of Brown Bear in Iran

The study was carried out from 2011 to 2013 with collecting the skulls from the museums of Iranian Department of Environment, private and hunter collections and bears perished in natures. We couldn't find any female samples from Zagros Mountain. In total 132 skulls were collected, selecting sixty two ones with specified gender and location in Alborz and Caucasia regions (Table 1). Sex of samples was determined based on the external features of skull including size, relative width of the skull, and development of the sagittal crest [37]. According to [37] there is a distinct suture between frontal and parietal in immature bear (cubs to 3 years), the condyle-basal length is 150-285 mm and the canines reach up to 15 mm in length. In adult female from 4 years onwards, the condyle-basal length is 283-285 mm and the length and height of the sagittal crest is up to 3 and 1.5 cm, respectively. In adult male from 6 years, the condyle-basal length is up to 313 mm and length and height of sagittal crest are 9-11 and 1.5-2.7 cm, respectively [37]. ImageJ software (ver 1.45s) was used to measure the distances on the skulls.

Geometric morphometric analysis: The ventral, dorsal and lateral sides of the skulls were photographed using a digital camera (Fuji HS10, 14 megapixels) installed on a tripod. A ruler was included in the images to allow the acquisition of a scaling factor. On the ventral, dorsal and lateral sides of cranium, 17, 13 and 16 landmark points were defined, respectively [10, 12, 18, 22, 38] (Fig. 2) (Table 2). Then TpsUtil 1.33 and TpsDig 2.10 [31, 32] software was used to digitize landmark points on 2D pictures. One side of skull adopted to digitize landmark point as used in previous studies [36]. This is a common method to reduce the time for data collection in symmetric structures [38]. The consensus shapes of both groups (males and females) were calculated using MorphoJ software.

The extracted data were superimposed using a Generalized Procrustes analysis (GPA) to remove non-shape variations [33]. Then, all data from three faces of both sexes were analyzed using principal components analysis (PCA), canonical variate analysis (CVA) and MANOVA. Discriminate Functional Analysis (DFA/Ttest Hotelling) was used to compare the shape of skull in two sexes i.e. survey of sexual dimorphism.

RESULTS

Dorsal view: DFA/T-test Hoteling analysis showed a significant difference in the dorsal view between male and female ($P<0.05$). The thin plate splint analysis in the deformation grid showed that the main difference is related to the occipital, zygomatic arch and sagittal crest regions (Fig. 3). Based on landmark displacements (landmarks 10 to 12), the males have elongated occipital bone and sagittal crest than in females. The male’s zygomatic arch region (landmarks 3 to 8) also showed a lateral shift resulting a bigger arch than that of female. The premaxilla in female was longer than that of male.

Lateral View: DFA/T test Hoteling analysis showed a significant difference in lateral view between two sexes (*P*<0.05). The comparison of skull shape between sexes showed that the premaxilla (landmarks 1 and 16), tooth row (landmarks 2 and 3) and nasal bone (landmarks 11, 13 and 16) of female was longer and wider than those of the male. In contrast, the sagittal crest (landmarks 8 and 9) is longer in male (Fig. 4).

Ventral View: DFA/Ttest Hoteling revealed a significant difference between two sexes in ventral view (*P*<0.05). The results showed that the condyle and occipital bone (landmarks 8 and 9) have displaced backward in male. Also, the zygomatic arch (landmark 5) was wider in male. Whereas, the tooth row (landmarks 3 and 4) in females was longer than that of male (Fig. 5).

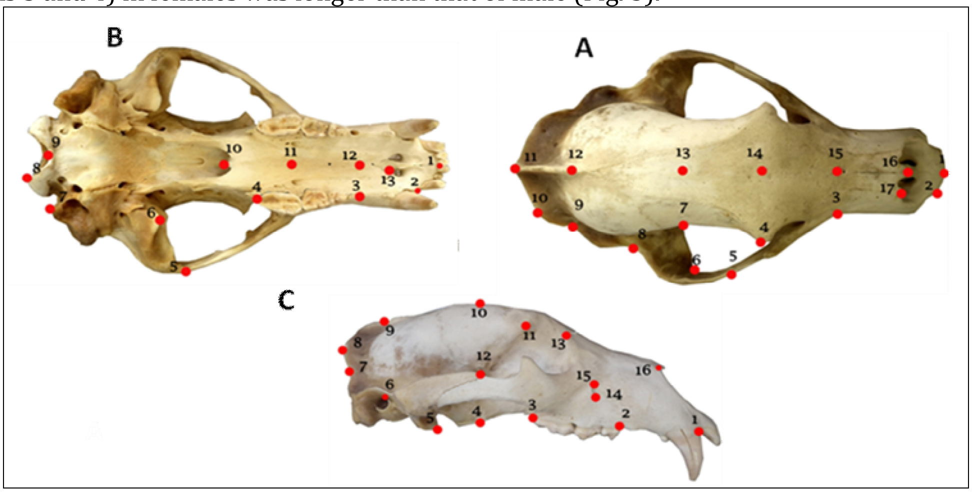

Fig. 2: Landmarks used in the morphometric analysis of bear crania in dorsal (a), ventral (b), and lateral (c) views

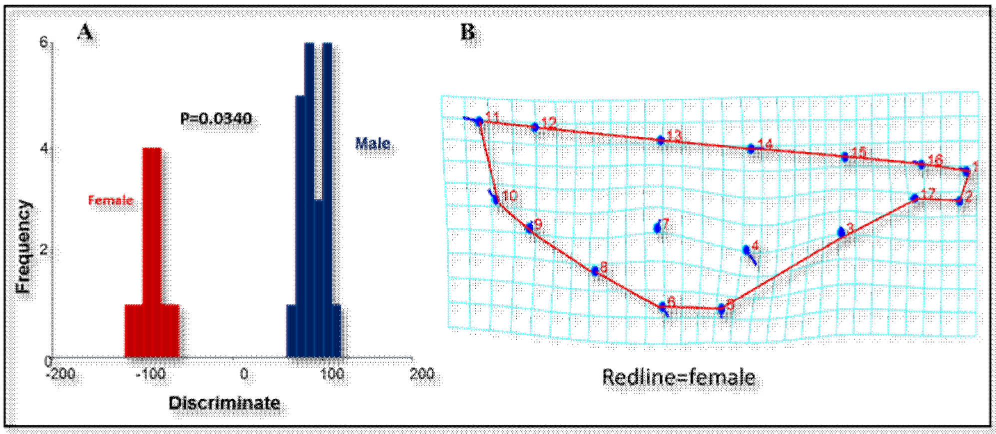

Fig. 3: DFA analysis and differences in dorsal view between male and female through the deformation grid

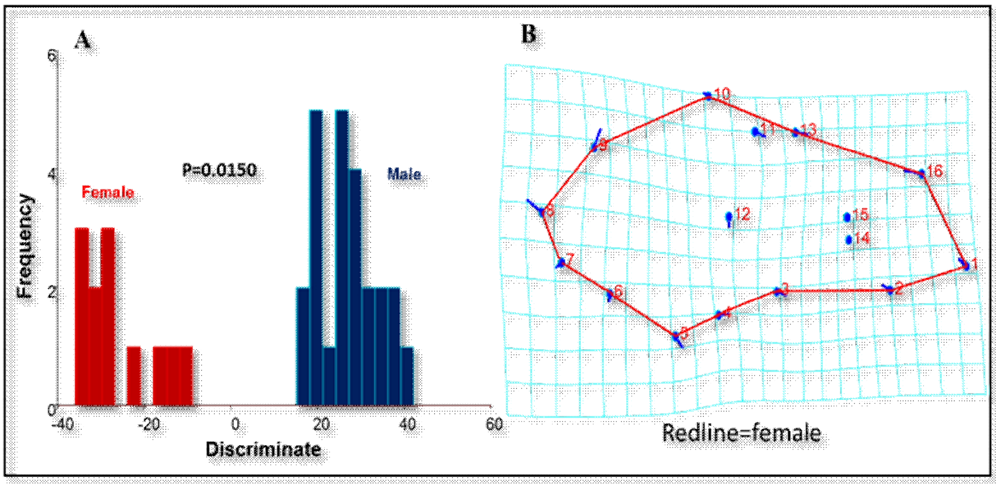

Fig. 4: DFA analysis and differences in lateral view between male and female through the deformation grid

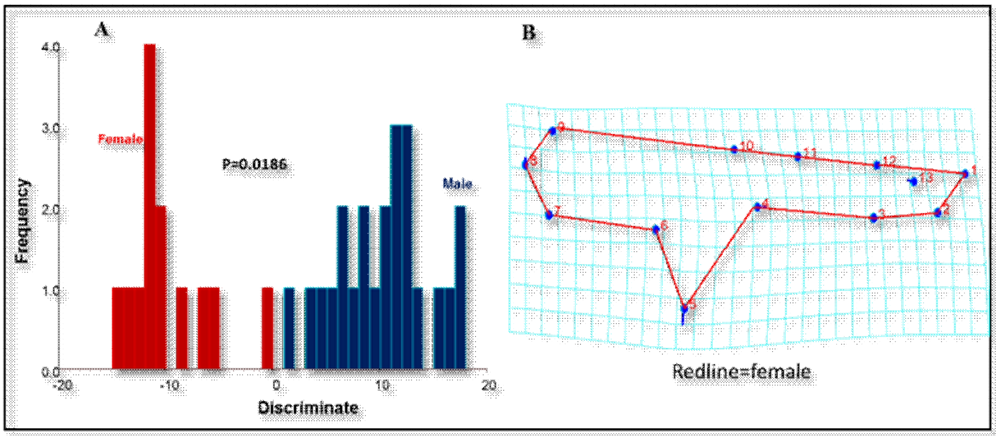

Fig. 5: DFA analysis and differences in ventral view between male and female through the deformation grid

Table 1: Number of skull analyzed

	Female			Male		
	Alborz	Zagros	Caucasus	Alborz	Zagros	Caucasus
Dorsal	12	0	2	22	15	9
Lateral	12	0	2	24	13	9
Ventral	12	0	2	24	13	9

Table 2: List of landmarks were used in morphometric analyses:

Dorsal View	
1	Edge of premaxilla seam in the septum
2	The edge of third incisor
3	Intersection between zygomatic arch and the maxilla
4	Highest point of the postorbital process
5	Squamosal-Jugal suture
6	The most inner point of zygomatic arch
7	The primary point of junction between squamosal and the braincase
8	Lowest point of the Squamosal curve
9	Lowest point of intersection of the Squamosal or parietal bone
10	Outline directly from landmark 8 and 9 to edge of parietal bone *
11	The highest point of the occipital crest
12	Line directly from landmark 9 to edge of sagittal crest*
13	Line directly from landmark 7 to Frontal suture*
14	Line directly from landmark 4 to Frontal suture*
15	Line directly from landmark 3 to nasal suture *
16	Midpoint the edge of nasal suture
17	Lowest point of the right nasal suture
Lateral View	
1	Front edge of the canine
2	Front edge of the fourth premolar
3	The end point of second molar
4	Highest point of the pterygoid
5	Highest point of the squamosal
6	Highest point of the external acoustic meatus
7	Innermost edge of the parietal bone
8	Outermost edge of the parietal bone
9	Line directly from landmark 6 to edge of sagittal crest*
10	Line directly from landmark 4 to central axis in frontal bone*
11	Highest point of the postorbital process
12	Midpoint between squamosal-jugal suture
13	Line directly from landmark 6 and 12 to frontal bone*
14	The earliest point of perforation from a socket
15	The end point of perforation from a socket
16	The end point of nasal bone suture
Ventral View	
1	The primary point of junction of incisor in premaxilla
2	Most posterior point of the third incisor

3	Front edge of the first premolar
4	The end point of the second molar
5	The midpoint between squamosal and jugal suture
6	Peak of the pterygoid bone
7	Peak of the para occipital bone
8	Peak of the occipital condyle
9	Most rostral point of the occipital condyle
10	Most posterior point of palatine bones suture
11	Intersection between palatine foramen and central axis prolong to the palatine suture*
12	Intersection between vertical line from landmark 3 and central axis of the skull*
13	The lowest point of the incisive foramen

DISCUSSION

Results show that males and females are clearly distinct in dorsal, lateral and ventral views. [27] Found sexual dimorphism in Giant Panda (*Ailuropodamelano leuca*) from the fourth month after birth. [19] predicted hyperallometry and sexual dimorphism in black bears (*Ursus americanus*). [21] Also showed sexual dimorphism in Black bear (*Ursus americanus*). [9] Found sexual dimorphism in polar bear (*Ursus maritimus*). [14] found sexual dimorphism in brown bear (*Ursus arctos*) skulls from unknown sources in Iranian natural history museum. According to the [2] environmental conditions is the major cause of variation in sexual dimorphism between populations. In addition, comparison of shape of two sexes showed the reinforcement and strength different parts in males' skull. The sexual dimorphism has the most noticeable effect in the size and shape of the skulls [15, 18].

According to the results, the main differences found in the occipital, zygomatic arch, sagittal crest, premaxilla and nasal bone regions between two sexes. In males, the zygomatic arch was longer in length and higher in height than in a female which is related to the size of their masseter and temporal is muscles. As mentioned before, larger zygomatic arch supports larger temporalis and masseter muscles [15, 23]. A bigger zygomatic arches causes the increase of the muscles' size and also the ability to move jaws forward and backward more efficiently [23]. Meanwhile, a bigger zygomatic arch can give more space to the coronoid excrescence in the lower jaw.

Males often prefer larger prey items than females as seen in strongly size-dimorphic species [29]. However, large predators not only take larger prey than smaller predators, they are also able to exploit a wider range of different prey sizes, which again has been documented for a variety of different animals [4, 29, and 35]. Strong bite forces are an important part of predator adaptations for a large-prey feeding ecology [4, 5, and 20].

Dimorphism can also be related to the social ecology of brown bears. Therefore, sexual dimorphism in brown bear depends on competition between sexes. In males, the frontal bone is bigger than that of female. In brown bears male-male competition in the mating season is severe [26, 28]. The thick frontal bones can be for the absorption of shocks to protect brain. Another explanation for the development of frontal bones and sinuses could be related to the bears' sense of smell [15]. The length of the maxilla and nasal bone in bears shows the strength of their smelling sense. The sense of smell is very important to the biggest land carnivore that has a weak sense of sight [25]. Comparison of this organ in two sexes shows more length in females, and probably more powerful sense of smelling in female core area due to avoid males infanticide behavior and other enemies.

Also, our results are in agreement with finding of [9], about sexual dimorphism in juvenile bears (before 3 years of age) because young male and female skulls are not simply recognizable. With increasing age, sexual dimorphism became more apparent in dependent young.

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