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CRANIOMETRIC DIFFERENTIATION OF GOLDEN JACKALS (*CANIS AUREUS* L., 1758) IN BULGARIA

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Summary: The skull morph metrics of golden jackal in Bulgaria was investigated using a collection of 293 skulls, 223 of them with known age and sex. Sixty-three measurements were taken for each specimen. Comparative variety and multivariate statistical analyses included standard statistics, t-test, QQ plots, Shapiro Wilk test, principal component analysis and discriminate analysis. All measurements were normally distributed. The skulls of male jackals were bigger than females, but with great overlap, in particular in juveniles and sub adults. The discriminate function classified correctly 97.3 % of male and 100 % of female jackals. The PCA revealed differences between skulls of Bulgarian and Dalmatian jackals, the skulls of latter being wider and shorter. Different criteria for golden jackal trophy awards could be suggested for adoption by CIC. Golden medal should receive trophies with score 26.5 CIC points, silver medal – 26, and bronze – 25.5.

Key words: golden jackal, Canidae, skull morph metrics, sexual dimorphism, multivariate analyses

Introduction

The golden jackal is one of the most widespread canidae species, occurring in southeastern Europe, northern and eastern Africa, and in large parts of Asia eastward to Thailand [5]. The northern border of the European resident population is along the Danube in Romania and former Yugoslavia [14]. In Europe the jackal occurs in North Italy, Slovakia, Austria, Hungary, South Poland, Slovenia, Croatia, Bosnia and Herzegovina, Albania, Montenegro, Macedonia, Serbia, Greece, Romania, its highest densities being on the Balkan Peninsula. The jackals are on the decline and listed as vulnerable animal in the national Red List [9] in Greece. The species has expanded its European distribution range, most notably in Bulgaria. There was 33-fold increase in the area inhabited by jackals between the 1960s and the 1980s and which now supports the largest jackal population in Europe [7, 14]. Vagrant animals have repeatedly been noticed in northeastern Italy, Slovenia, Hungary, Austria, Slovakia, and Macedonia [3, 14].

Golden jackals are becoming a species of great economic impact in Europe due to their increasing numbers and their influence on game losses. However, their taxonomy and morph metric are poorly known. Twelve subspecies are distinguished across the range. However, there is much variation and populations need to be re-evaluated using modern molecular techniques [28]. Craniometric studies on golden jackal are scarce, including small number of measurements and no statistical analyses were performed. The only exception in Europe is studying on variability of the golden jackals of Dalmatia [15]. Some craniometrical data could also be found in [5]. Understanding patterns and differences in jackals' craniometrical are crucial for their taxonomy and could contribute to their management and conservation. The aim of the present study is to reveal the differences between golden jackal skulls in Bulgaria and to compare the skulls of Bulgarian jackals with these from other parts of the golden jackal range.

Material and Methods

The study was based on 228 golden jackal skulls from Bulgaria. The most of them (95) was collected between 1998 and 2006 in three main regions in Bulgaria – Yambol, Veliko Tarnovo and Burgas, but also skulls from total 20 different sites were included in the analysis. Another 62 skulls were from collection of Vassilev, collected in the end of 1980s, 35 were from National Museum of Natural History. 22 skulls were measured from students in Wildlife Management Dept. during their master's degree work. Measurements of other 65 skulls, published by other authors, from Bulgaria and the other parts of the species range, were used for comparison [5, 15].

Specimens were aged on the basis of upper incisive teeth weariness [16], and for 27 of them also by counting the annual rings of canine teeth cement [13]. The accuracy of the first method is 1 year until the age of 3 years [23]. Only 6 animals were classified as 4 years old and 3 – as 5+ years old, because all of the teeth were worn out. The error could be more than 1 year for these animals, but their number is too small to influence the results. The second method is much more accurate, but time consuming and expensive, requiring special equipment. It determines the exact age if there is no error in counting annual rings. Rajchev compared both methods and excluding 3 cases they gave the same results [23]. Harris *et al.* suggested for using the method of the weariness of teeth for the age determination of badgers. The method was as reliable as counting the annual rings of canine teeth cement [10].

A total of 67 measurements, 47 on cranium and 20 on mandible (Fig. 1) were taken for each skull using digital caliper to the nearest 0.1 mm. Measurements were chosen according to [35] and correspond to those taken in previews studies [5, 8, 11, 12, 15, 25, 29, 36, 37]. The full description and index of measurements are shown in

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Table 1.

One variate and multivariate statistical analyses were performed using R [22]. All plots and figures were produced in R, some of them using package lattice [27]. For multivariate analyses package MASS [34] was used. Standard statistics comprised mean and standard deviation for sub adult and adult male and female jackals. QQ plots and Shapiro-Wilk did testing for normality. Skull measurements between males and females were compared using t-test.

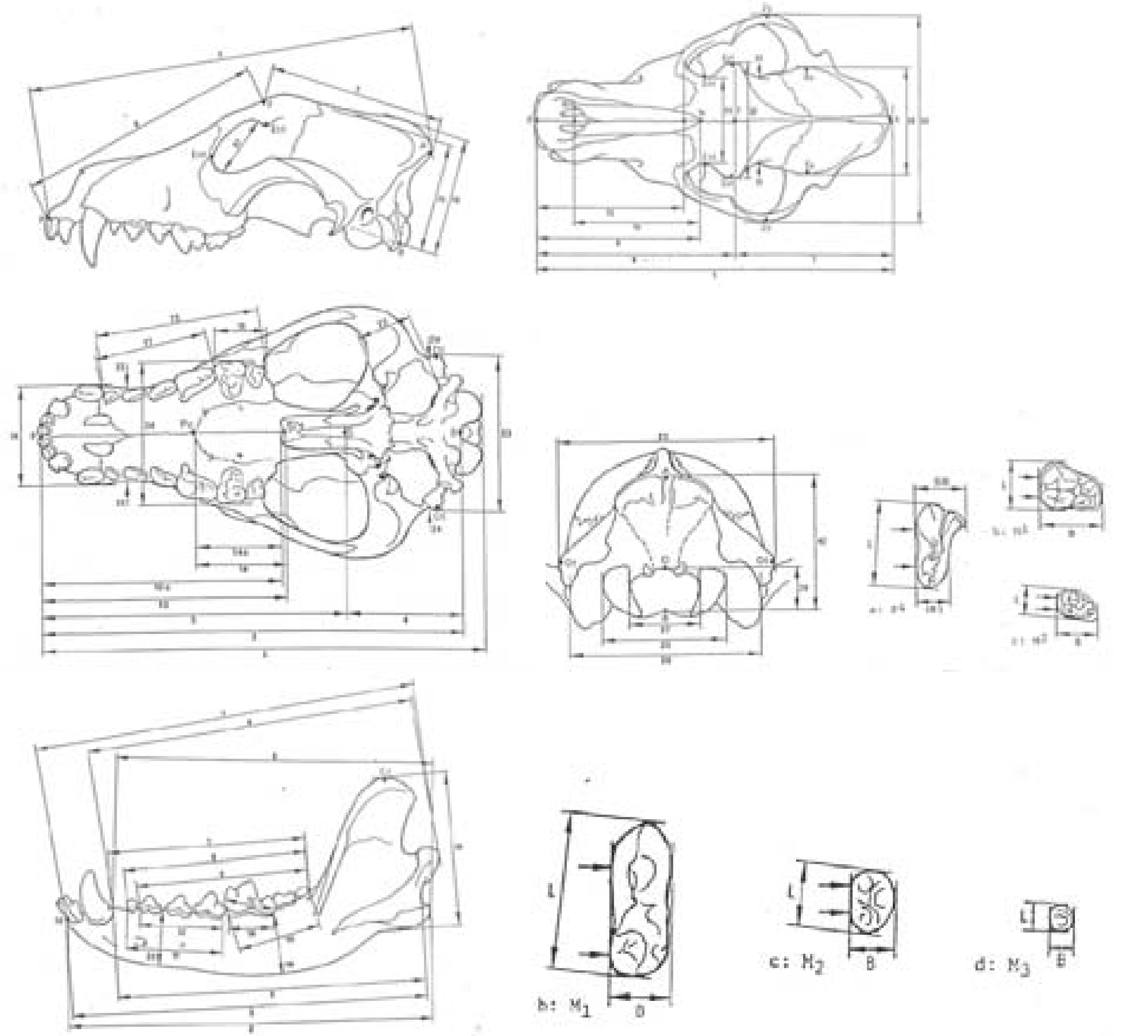

Fig. 1. Skull measurements of golden jackals.

Since multivariate analyses require complete data sets, multiple regression models, using the code provided by Claude [4], estimated those missing cranial measurements of each specimen. Principal component analysis was performed to look for patterns in distribution of jackal skulls. For differentiation between males and females, also linear discriminate analysis was applied. Because the ratio from largest to smallest value was relatively small and measurements were taken on the same scales the data were not log transformed neither scaled before applying analyses [17].

Results and Discussion

All skull measurements were tested for normality using QQ plots and Shapiro-Wilk test. There was no reason to reject the null hypothesis that all measurements had normal distribution (Fig. 2).

In most skull traits juveniles, i.e. jackals between 7-10 months differ from older jackals (Fig. 3). It is a reasonable to determine another age group of sub adult jackals. Golden jackals reach sexual maturity at age of 10-11 months [33], but they rarely reproduce at this age. In Tanzania 70 % of known surviving pups were observed. They were helping with the next year's litter and thus did not rear their own offspring. Retaining helpers potentially increases the parents' reproductive success, that is, it increases the parents' chances of passing on their genes to future generations [18]. Probably only jackals in reproductive age reach full growth of the skull. Some craniometrical dimensions of the 1-year old jackals differed from that of the older jackals, for example zygomatic breadth and mastoid breadth. Nevertheless, most of the traits did not show any significant differences between sub adults and adult jackals. We compared skulls of males and females with t-test for sub adult and adult jackals, altogether, excluding only juveniles. The comparison between sexes of biometric data showed significant differences in almost all measurements ($p<0.001$) (Table 1).

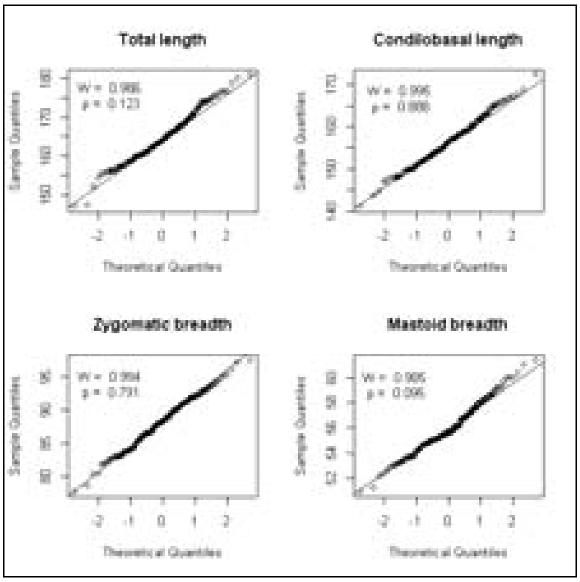

Fig. 2. QQ plots and Shapiro-Wilk tests for normality on 4 main skull dimensions. W – test statistic, p – p-value.

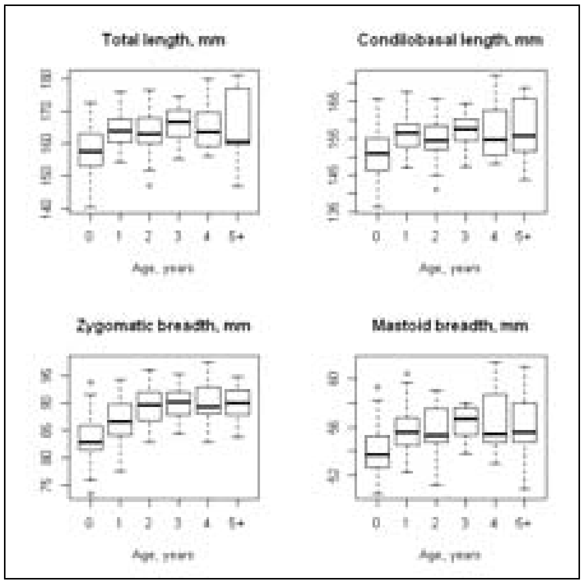

Fig. 3. Skull measurements' dependence on the age of jackals

Although there were differences between sexes in almost all dimensions males and females overlapped and there were no clear borders between them. Multivariate statistical methods were used to search for existing patterns in the distribution of skulls. Principal component analysis (PCA) was performed on all individuals, including juveniles and sub adults. Using PCA was necessary to reduce the variable space to dimensions that express most of the variation. The first two principal components explained 82.7 % of the variation, 79.4 % for the first and only 3.3 % for the second. As one could see from the factor loadings, the first principal component was mainly associated with length measurements and contributed to the size (Fig. 4). The second principal component also was associated with size, mainly breadth of the skull. High correlation between variables justified using the PCA. Comparing results from analysis (Fig. 5), there was clear that grouping was due to sex differences and didn't depend on the age of the animals neither on the site. Only one group of juveniles, these below 6 months of age, differ from the other. Older males differ from females, but sub adults and juveniles could have been mistaken with females.

The discriminant analysis indicated significant differences between sexes ($W = 0.83$; $F = 3.75$; d.f. = 70,54; $p < 0.0001$, $D = 3.9$). Only the skulls of adult and sub adult jackals with known sex were included in the analysis. The results showed almost 100 % correct discrimination between sexes. Only 2.7 % of males were classified as females and 100 % of females were classified correct (Fig. 7). The discriminate function could be used for classification of unknown skulls, but should be verified before. The total number of skulls and included measurements didn't allow testing. Although not of practical use, the analysis showed that the skulls of adult males and females could be separated.

Discriminant analysis is a very robust method with respect to lack of multi normality and equality of group dispersions [21]. The high ratio between calculated and observed degree of correct classifications showed that possible lack of fulfillment of the assumptions behind the method had not influenced the results.

Sexual size dimorphism is common among vertebrates, males usually being the larger sex [24]. Recently the extreme dimorphism in Mustelidae [20, 36] and Pinnipedia [31] and the reversed dimorphism in predatory birds [1, 30] have attracted particular interest and new theories have been proposed [20, 36, 37].

Although sexual dimorphism of skulls was quite clear, there was a great overlap in all measurements. The high significance of the t-test results was due to large samples. Such sexual dimorphism of golden jackal skulls, with males a little bit larger than females, could be explained with monogamous reproductive system of golden jackal and the presence of male parental care [18, 19]. Golden jackals form pair-bonds that are characterized by friendly behavior and last the 6 to 8 years of their usual lifespan. There is little sexual dimorphism, either physically or behaviorally, and they share equality in most activities, such as marking and defending their territory, foraging and resting [18]. Such degree of sexual dimorphism in Canidae was found also in other studies [11, 12, 29].

Table 1. Sample statistics for the golden jackal skull measurements and results of the t-test.

№	Measurements	Index	males (n=92)		females (n=56)		p
			mean	sd	mean	sd	
1a	Maximal length	Maxl	168.7	6.3	164.2	4.6	0.000
1	Total length	Tl	166.4	6.4	161.9	4.7	0.000
2	Condylobasal length	Cbl	158.0	5.6	153.7	4.0	0.000
3	Basal length	Bl	149.1	5.3	145.2	3.9	0.000
4	Basicranial axis	Bca	43.5	1.7	42.1	1.3	0.000
5	Basifacial axis	Bfa	106.3	4.2	103.5	3.5	0.000
6	Neurocranium length	Ncl	89.0	3.0	86.5	2.2	0.000
7	Upper neurocranium length	Uncl	76.7	3.0	74.5	2.7	0.000
8	Viscerocranium length	Vcl	77.7	3.9	75.8	3.1	0.001
9	Facial length	Fl	96.3	4.3	93.9	3.4	0.000
10	Greatest length of the nasals	Nasl	59.7	3.7	57.9	3.3	0.002
11	Length of braincase	Brcl	80.2	2.9	77.6	2.3	0.000
12	Snout length	Snl	67.2	3.5	65.2	2.9	0.000
13	Medial palatal length	Mpl	79.4	3.0	77.5	2.6	0.000
13a	Palatal length	Pl	78.1	2.9	76.1	2.5	0.000
14	Length of the horizontal part of the palatine	Mplh	29.5	2.0	29.2	1.8	0.338
14a	Corresponding to 13a	Plh	28.1	1.6	27.9	1.6	0.397
15	Length of the chesktooth row	Lp1m2	58.4	2.1	57.3	1.7	0.000
15a	Length from oral border of C^1 to aboral border of M^2	Lc1m2	68.6	2.6	67.2	1.9	0.000
16	Length of the molar row	Molr	17.7	1.0	17.4	0.9	0.096
17	Length of the premolar row	Prmr	43.3	1.9	42.4	1.5	0.001
18	Length of the carnassial, measured at the cingulum	Lp4	17.2	0.7	16.7	0.7	0.000
18a	Greatest breadth of the carnassial	Bp4	9.4	0.5	9.3	0.6	0.328
19	Length of the carnassial alveolus	Lp4a	16.3	0.8	15.9	0.8	0.001
20	Length of M^1	Lm1	12.8	1.1	12.5	0.9	0.122
20	Breadth of M^1	Bm1	14.4	0.9	14.0	0.9	0.004
21	Length of M^2	Lm2	7.4	0.5	7.3	0.6	0.264
21	Breadth of M^2	Bm2	9.8	0.7	9.4	0.7	0.002
22	Greatest diameter of the auditory bulla	Bull	24.8	1.9	24.6	1.2	0.256
23	Greatest mastoid breadth	Mst	56.4	2.0	55.2	1.5	0.000
24	Breadth dorsal to the external auditory meatus	Mstau	55.6	2.0	54.4	1.4	0.000
25	Greatest breadth of the occipital condyles	Occb	31.5	1.3	30.7	1.3	0.000
26	Greatest breadth of the bases of paraoccipital processes	Poprb	43.3	1.5	42.5	1.3	0.001
27	Greatest breadth of the foramen magnum	Fmagb	17.7	0.7	17.2	0.9	0.000
28	Height of the foramen magnum	Fmagh	13.5	0.9	13.3	1.1	0.221
29	Greatest neurocranium breadth	Skb	52.5	1.8	51.6	1.3	0.000
30	Zygomatic breadth	Zyg	89.2	3.8	86.7	3.6	0.000
31	Least breadth of skull	Pob	28.4	2.1	28.1	2.1	0.432

№	Measurements	Index	males (n=92)		females (n=56)		p
			mean	sd	mean	sd	
32	Frontal breadth	Fb	42.2	3.0	41.7	2.8	0.322
33	Least breadth between the orbits	Iob	26.3	1.8	25.5	1.7	0.010
34	Greatest palatal breadth	Palb	53.9	1.9	52.7	1.6	0.000
35	Least palatal breadth	Lpalb	28.7	1.5	27.9	1.0	0.000
36	Breadth at the canine alveoli	Rb	29.7	1.4	28.7	1.0	0.000
37	Greatest inner height of the orbit	Orb	31.0	1.3	30.4	1.2	0.002
38	Skull height	Skh	48.5	1.8	47.8	2.0	0.028
39	Skull height without the sagital crest	Skhs	44.9	1.7	44.2	2.0	0.030
40	Height of the occipital triangle	Otrh	38.8	1.8	38.0	1.4	0.004
	Mandible						
1	Total length: Condyle process - Infradentale	Mand	121.9	4.6	118.6	3.5	0.000
2	Length: Angular process - Infradentale	Mlapid	123.2	4.7	119.5	3.6	0.000
3	Length: Indent Btw APr and CondPr - Infradentale	Mlapcpid	117.7	4.4	114.6	3.2	0.000
4	Length: Condyle process - Aboral border Canine alveolus	Mlcpca	107.1	4.2	104.1	3.3	0.000
5	Length: Indent Btw APr and CondPr - AbBo Canine alveolus	Mlapcpca	103.1	4.0	100.2	3.0	0.000
6	Length: Angular process - AbBo Canine alveolus	Mlapca	108.5	4.5	105.6	3.7	0.000
7	Length: AbBo Canine alveolus - M_3	Mlcam3	69.0	2.4	67.7	1.9	0.001
8	Length of the chesktooth row, M_3-P_1	Mlp1m3	65.5	2.1	64.5	1.8	0.001
9	Length of the chesktooth row, M_3-P_2	Mlp2m3	60.7	2.2	59.8	1.8	0.006
10	Length of the molar row, M_1-M_3	Mmolr	31.8	1.3	31.0	1.2	0.000
11	Length of the premolar row, P_1-P_4	Mprmr	33.9	1.4	33.4	1.2	0.029
12	Length of the premolar row, P_2-P_4	Mlp2p4	29.2	1.3	28.7	1.1	0.013
13	Length of the carnassial measured at the cingulum	Mlm1	19.2	0.7	18.7	0.7	0.000
13a	Breadth of the carnassial measured at the cingulum	Mbm1	7.7	0.5	7.4	0.4	0.000
14	Length of the carnassial alveolus	Mlm1a	18.1	0.9	17.6	0.7	0.000
15	Length of M2 measured at the cingulum	Mlm2	8.7	0.5	8.6	0.5	0.190
15a	Breadth of M2 measured at the cingulum	Mbm2	6.2	0.4	6.0	0.4	0.000
16	Length of M3 measured at the cingulum	Mlm3	4.6	0.3	4.7	0.4	0.716
16a	Breadth of M3 measured at the cingulum	Mbm3	4.0	0.3	3.9	0.3	0.035
17	Greatest thickness of the body of jaw bel. M_1	Mjaw	8.6	0.5	8.4	0.5	0.026
18	Heigth of the vert. ramus: Angular Process - Coronion	Manh	48.6	2.6	46.7	2.2	0.000
19	Heigth of the mandible behind M_1	Mhm1	18.5	1.1	17.8	0.8	0.000
20	Heigth of the mandible between P_2 and P_3	Mhp2	15.2	1.0	14.8	0.7	0.001

For comparison between jackal skulls from different parts of the range14 skull traits were used – Cbl, Nasl, Lp4, Bull, Skb, Zyg, Pob, Fb, Iob, Palb, Rb, Skh, Mand, Mlm1. Jackal skulls from Bulgaria were compared to the skulls from other parts of the golden jackal range – Croatia (Dalmatia), Greece, Hungary, Turkey, Russia, Georgia, Tunisia, Libya, Algeria, Morocco, Egypt, Ethiopia and Sudan. The PCA revealed four different groups – Dalmatian jackals, African jackals, African jackals from subspecies *Canis aureus lupaster* Hemprich and Ehrenberg, 1833 and jackals from Europe and Caucasus (Fig. 6). Skulls of African jackals from the subspecies *lupaster* are bigger with more elongated shape and broader skull. Many authors considered this jackal as different species [6, 26]. Dalmatian jackal skulls are broader with shorter length. The same differences between Dalmatian, Bulgarian and African jackals were discovered by Kryštufek and Tvrtković [15]. With numerous samples from Bulgaria and using PCA, we showed that Bulgarian jackals covered both African and Dalmatian jackals on the plot. The skulls of Bulgarian jackals didn't differ from the skulls from Europe and Minor Asia. These results could be explained with historic changes in distribution, geographical isolation, founder effect for small isolated populations as Dalmatian, different ecological conditions, competition with wolf and human pressure on golden jackal populations [15, 32]. It is clear however that there is no reason to consider these morphological differences as prove for existence of more than one subspecies on the Balkans and adjacent European countries. Most of the golden jackal's subspecies are controversial and not recognized. Genetic studies so far revealed that jackals in Europe are genetically similar [32, 38]. There is a need for more detailed revision on golden jackal taxonomy. Probably most of the golden jackal subspecies – *hungaricus* (Ehik, 1938), *escedensis* Kretzoi, 1947, *dalmatinus* (Wagner, 1841), *balcanicus* (Brusina, 1892), *caucasica* (Kolenati, 1858) , *maroccanus* (Cabrera, 1921), *graecus* (Wagner, 1841), recognized in the past, should be considered as one subspecies – *moreotica* I. Geoffroy Saint-Hilaire, 1835.

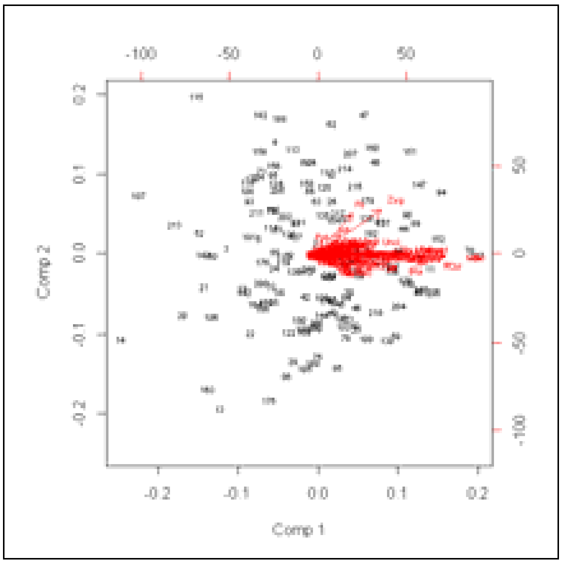

Fig. 4. Biplot of the PCA with factor loadings of variables and factor scores of individuals.

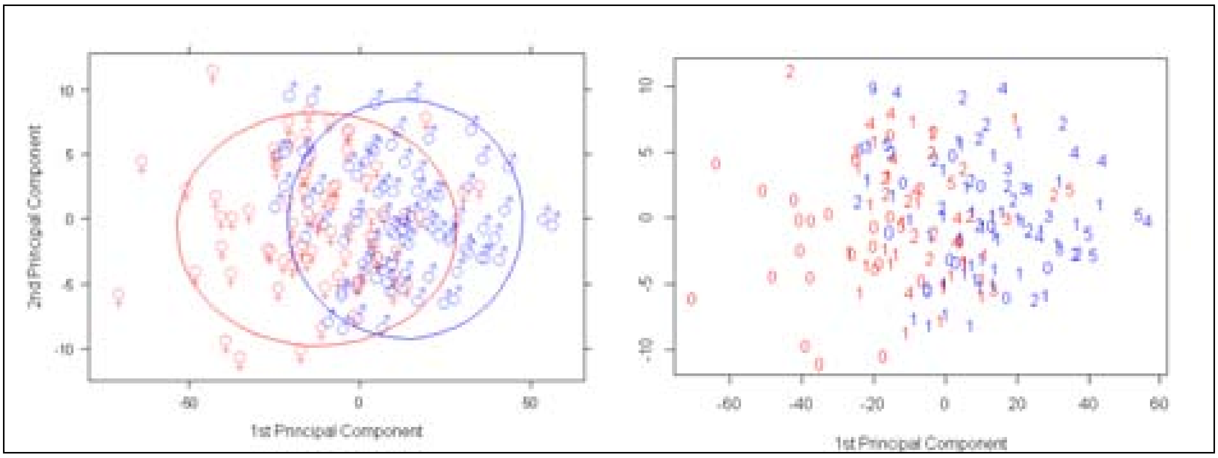

Fig. 5. Results from the principal component analysis. Ellipses show 95 % confidence interval for the group. On the second plot numbers mean age of the animal

Another practical reason for measuring jackal skulls is trophy evaluation by CIC formulae of measuring trophies. There was lack of criteria for awarding jackal trophies with medals. Angelescu [2] proposed such criteria based on 31 male and 42 female golden jackal skulls, including juveniles. These criteria were adopted by CIC “Exhibitions and Trophies” Commission but the decision was arbitrary and not supported by analysis of abundant material. It is normal that no more than 10 % of skulls that could be awarded with golden medal. Analysis of our material (137 skulls from adult jackals only) suggested increasing criterion for award with medal at least with 0.5 points (Fig. 8). If these criteria were adopted by CIC, about 15 % of jackal trophies would be awarded with golden medal, 20 % - with silver, and 20 % - with bronze. According to current criteria 75 % of trophies from adult jackals will receive medals, 35 % - gold, 20 % - silver, and 20 % - bronze.

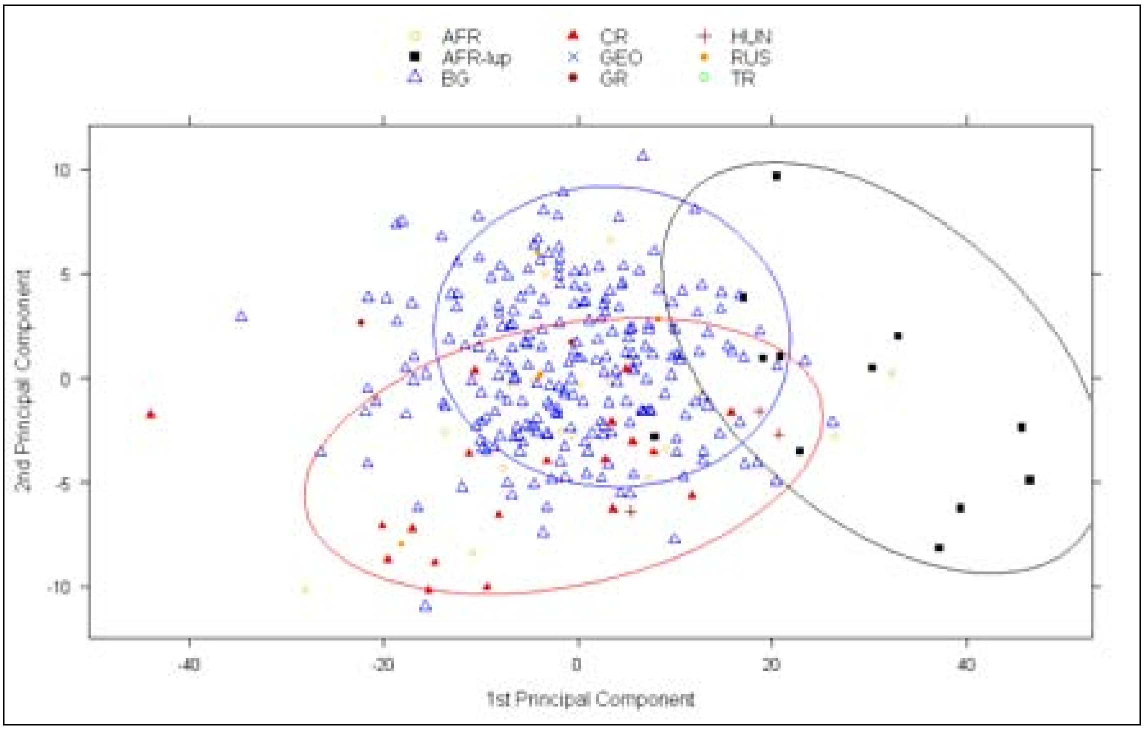

Fig. 6. Results from the PCA, comparing skulls from different parts of the golden jackal range. Ellipses show 95 % confidence interval for each group – Bulgaria, Dalmatia, Africa – subspecies *lupaster*.

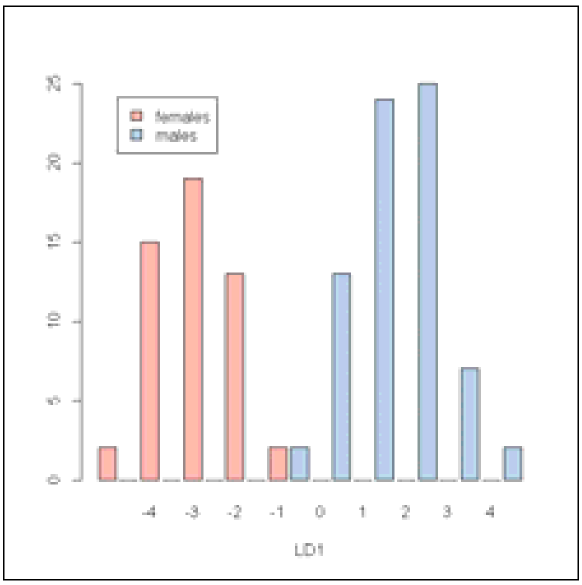

Fig. 7. Results from discriminant analysis showing separation between males and females golden jackals.

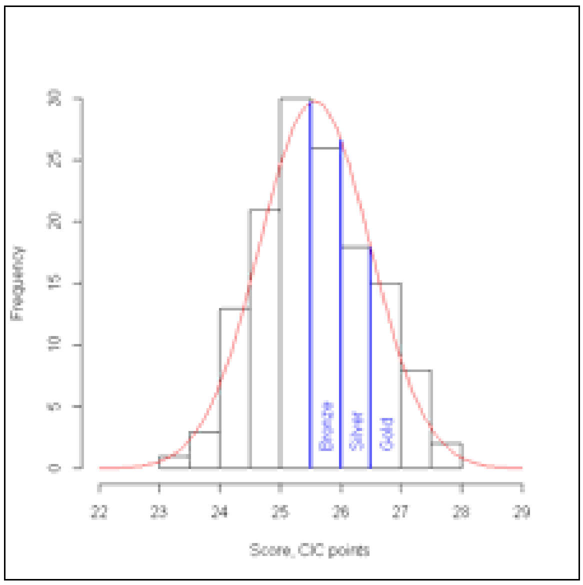

Fig. 8. Distribution of golden jackal trophies from Bulgaria according to CIC system of evaluation. Red line is normal approximation curve. With blue lines are marked suggested scores for award with medals

Conclusions

Golden jackal skulls from Bulgaria showed homogeneity in size and form. The comparison between sexes of biometric data showed significant differences in almost all skull measurements ($p<0.001$), but there was overlap and no clear differentiation. Skulls of adult males are a little bit larger than of adult females. By discriminant analysis, it was possible to find linear combination of measurements that best discriminate male and female skulls of adult and sub adult jackals. Differences in skull measurements were due to sexual dimorphism and didn't depend on site or age of adult jackals. Only juveniles below 6 months of age could be clearly separated by PCA.

Skulls of Bulgarian jackals didn't differ from these of the other parts of golden jackal range in Europe, except from Dalmatian jackals, which were broader, and subspecies *lupaster* in Africa, which was considered different species. However, there is no reason to be recognized more than one subspecies of golden jackal in Europe. More studies are needed to establish the taxonomic structure of golden jackal.

Different criteria for golden jackal trophy awards could be suggested for adoption by CIC. Golden medal should receive trophies with score 26.5 CIC points, silver medal – 26, and bronze – 25.5.

Acknowledgements

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