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MULTIVARIATE ANALYSIS OF CRANIOMETRIC CHARACTERS IN BULGARIAN CHAMOIS

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ABSTRACT – A craniometrical study was carried out to examine the skull characteristics of the Bulgarian chamois ***(Rupicapra rupicapra balcanica)*** **(1)** to assess whether any difference between sexes is detectable and **(2)** to compare the Bulgarian material with other already described chamois populations occurring in other European regions. Results of multivariate analyses run on seven craniometrical characters showed sexual dimorphism in the Bulgarian sample. Discriminant Analysis performed on individuals from different populations showed that the positions of the samples in discriminant space were approximately congruent with their geographical position. Principal Component Analysis revealed that the main factor of variation among groups is a size factor. The structure of loadings on PC-II and PC-III and the amount of total variability expressed by these two components suggested also shape differences. Results from multivariate analyses carried out on the means of the characters confirmed these patterns. A dimensional cline for the genus ***Rupicapra*** is suggested,, the north-east chamois populations showing the largest skulls and the south-west populations having the smallest sizes.

Key words: Bulgarian chamois, Europe, craniometry, sexual dimorphism, geographic variation.

RIASSUNTO – *Analisi multivariata dei **caratteri** craniometrici nel **carnoscio bulgaro*** – Uno studio dei caratteri cranici del camoscio bulgaro ***(Rupicapra rupicapra balcanica)*** è stato effettuato al fine di 1) valutare il grado di dimorfismo sessuale; 2) confrontare il campione bulgaro con altre popolazioni di camoscio europeo già descritte in letteratura. I risultati delle analisi multivariate effettuate su sette caratteri craniometrici hanno mostrato l'esistenza del dimorfismo sessuale nel camoscio bulgaro. L'analisi discriminante effettuata su individui appartenenti a diverse popolazioni ha mostrato che la posizione dei campioni nello spazio discriminante è congruente con la loro posizione geografica. Canalisi della componente principale ha rivelato che il fattore che spiega la maggiore variabilità fra gruppi è di tipo dimensionale. La struttura dei pesi delle variabili su PC-II e PC-III e la quantità di variabilità spiegata da queste due componenti suggerisce anche differenze di forma. I risultati delle analisi rnultivariate effettuate sulle medie dei caratteri, confermano questa tendenza. Viene ipotizzata la presenza di un cline dimensionale per il genere ***Rupicapra,*** in cui i camosci nord-orientali mostrano i crani pih grandi e quclli sud-occidentali possiedono le dimensioni minori.

Parole chiave: camoscio bulgaro, Europa, craniometria, dimorfismo sessuale, variazione geografica.

INTRODUCTION

Studies on the craniometric characteristics of the chamois *Rupicapra* spp. have been carried out by many authors (e.g. Couturier, **1938;** Briedermann & Still, **1976;** Hrabe & Koubek, **1982, 1984;** Scala & Lovari, **1984)** employing different sets of measurements and sometimes without specifying sex and age in the samples. At present there are still geographical populations not morphologically characterized, which considerably hampers an exaustive analysis of the craniometric similarity and divergence among different populations within the distribution range of the species. Furthermore, multivariate analyses on east European chamois skulls have never been carried out.

A recent paper (Genov et al., **1990)** on the status and distribution of the chamois in Bulgaria established that about **1600** individuals inhabit the four massifs of the country. The hitherto published craniometrical data on *Rupicapra rupicapra balcanica* were based on three skulls of adult individuals from Yugoslavia and Greece (Martino in Couturier, 1938), five skulls from the same countries (Bolkay in Couturier, **1938)** and on seven skulls with a good craniometrical description, only one of which from Bulgaria (Couturier, **1938).**

The aim of this study is to examine the skull characteristics of the Bulgarian chamois, hereinafter called R. *r. balcanica,* (1) to assess whether any difference between sexes is detectable and (2) to compare our material with the already described populations occurring in other European regions.

MATERIAL AND METHODS

The craniometrical analyses of the Bulgarian chamois were carried out on 18 skulls (10 males and eight females). All the skulls were from adult individuals, with complete dentition and whose skull growth was terminated i.e. chamois older than 4 years (Lovari & Scala, **1980).** Most of the material was obtained from private collections and three skulls from the National Museum of Natural History, Sofia. All the specimens were from Pirin, Rila, Rhodope Mountains and Balkan Range; most of them had been shot and one was found dead. Seven characters were taken from the skulls of the Bulgarian sample, measured up to 1 mm precision: 1) total length of the skull; 2) length of nasal bone; 3) maximum width of the skull at fronto-parietal suture; 4) maximum width of the skull; 5) vertical diameter of the eye socket; 6) condylo-basal length of the skull; 7) maximum width of the skull at the parieto-occipital suture.

To compare our samples with those from other populations, we used data from Couturier (1938), who provided individual measurements on *R.rupicapra cartusiana* males (n = 8) and females (n = 6) from Chartreuse

Massif and *R. pyrenuica pyrenaica* females (n = **13)** from Pyrenees and from Scala & Lovari **(1984)** who provided individual measurements on R. *pyrenaica ornata* (n = 9) from Apennines and *R.p. pyrenaica* (n = 9) males from Pyrenees. We also used the means of characters measured by Hrabe & Koubek **(1982** and **1984),** Koubek & Hrabe **(1983)** and Koubek, Weber & Hrabe **(1985)** on *R.r. rupicapra* males (n = 47) and females (n = 26) from the Jeseniky Mts., eastern Sudetes, *R.r. tatrica* males (n = 58) and females (n = 38) from the Tatra Mts., *R.r. caucasica* males (n = 30) and females (n = **13)** from Great Caucasus and *R.r. carpatica* males (n = 55) and females (n = **12)** from the Romanian Carpathians. All the analyses on these populations were performed on the craniometrical characters taken by all the authors, i.e. the above mentioned variables 1 to 5 and (6) horizontal diameter of the eye socket.

Data were log-transformed to allow linear relationships between them. The basic descriptive statistics of *R.r. balcanica* were calculated separately for each **sex.** Sexual dimorphism was studied by help of univariate as well as multivariate techniques. Covariance matrices were calculated and Principal Component Analysis (PCA) applied to examine the overall patterns of variation. Multivariate relationships among groups were evaluated using PCA that allowed the description of the multivariate spatial distribution of the observed values with a cartesian system of vectors (PC) (Fowler & Cohen, **1993).** Discriminant Analysys (DA) was

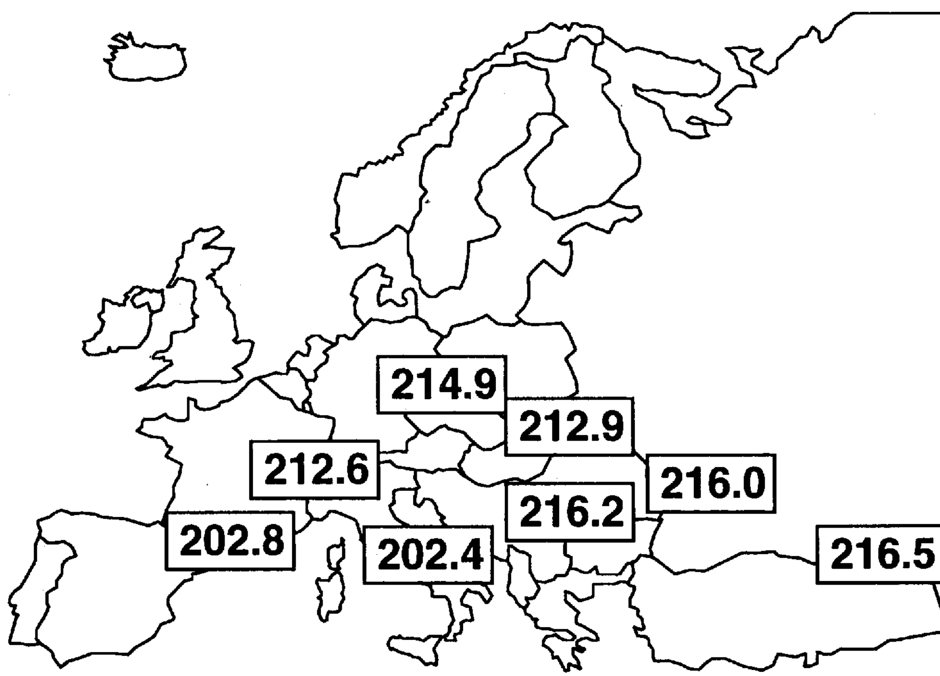

Fig. **1 – Population means** of **total length of the skull in *Rupicapra* spp. males.**

Tab. 1a – Mean values (in mm) of the studied skull characters of Bulgarian chamois *R.r. balcanica* and standardized vector coefficients of the seven variables for the discriminant function separating the Bulgarian chamois according to sex Sample sizes are given in brackets.

CHARACTERS	MALES (n = 10) MEAN	S.D.	FEMALES (n = 8) MEAN	S.D.	t-TEST	COEFFICIENTS
1. Total length	216.22	3.66	211.50	5.49	*	-0.07643
2. Nasals length	67.01	2.37	62.42	4.44	*	0.28931
3. Width at fronto-parietal suture	67.02	2.37	65.55	1.68	n.s.	-0.03024
4. Maximum width	111.40	2.48	105.45	2.74	**	0.77391
5. Vertical eye diameter	38.36	0.94	38.70	0.99	n.s.	-0.46140
6. Condylobasal length	203.05	3.68	197.37	6.44	*	0.25187
7. Width at parieto-occipital suture	21.99	2.42	18.45	1.33	**	0.48118

Tab. 1b – Mean values (in mm) and S.D. of the skull characters of European chamois populations. Sample sizes are given in brackets. Characters numbers 1 to 5 as in Tab. 1a, character 6 = horizontal diameter of the eye socket.

MALES	1	2	3	4	5	6	REFERENCES
MALES							
ornata	202.4	64.4	60.4	105.0	36.7	35.4	Scala & Lovari, 1984
(n = 9)	10.8	4.8	2.2	4.5	1.2	0.7	
pyrenaica	202.8	63.5	61.0	104.3	36.4	36.4	Scala & Lovari, 1984
(n = 9)	7.5	4.6	1.7	2.4	2.0	1.3	
carpatica	216.0	71.8	66.5	113.8	38.2	40.3	Koubek et al., 1985
(n = 55)	8.2	4.7	2.1	3.8	1.1	1.4	
tatrica	212.9	64.7	65.6	110.1	37.6	39.9	Hrabe & Koubck, 1984
(n = 37)	6.1	3.4	1.6	4.5	1.6	1.2	
nipicapra	214.9	67.9	63.1	106.5	35.7	37.6	Hrabe & Koubek, 1982
(n = 26)	5.7	3.7	1.0	3.6	0.8	1.0	
caucasica	216.5	73.4	64.3	110.0	36.8	39.3	Koubek & Hrabe, 1983
(n = 26)	5.2	4.4	2.6	3.8	1.4	1.4	
cartusiana	212.6	69.3	60.6	110.4	36.5	37.6	Couturier, 1938
(n = 8)	3.1	6.6	1.1	2.3	1.1	0.6	
balcanica	216.2	67.0	67.0	111.4	38.4	36.3	this paper
(n = 10)	4.0	2.1	2.1	2.5	0.7	0.6	
FEMALES							
pyrenaica	197.4	63.8	60.4	103.4	34.7	36.3	Couturier, 1938
(n = 13)	4.1	5.0	1.1	5.7	1.2	1.0	
carpatica	2163	68.0	65.2	111.9	37.7	40.0	Koubek et al., 1985
(n = 12)	1.2	3.4	2.0	4.2	1.4	1.5	
tatrica	211.1	63.5	64.3	106.3	38.0	39.4	Hrabe & Koubek, 1884
(n = 16)	4.5	3.9	1.1	3.7	1.2	0.9	
nipicapra	212.0	65.4	63.0	104.5	36.2	37.7	Hrabe & Koubek, 1982
(n = 8)	5.1	3.8	1.6	3.1	2.2	0.9	
caucasica	210.3	70.6	62.8	106.7	36.5	38.1	Koubek & Hrabe, 1983
(n = 11)	5.5	3.9	1.4	6.1	1.5	1.8	
cartusiana	206.3	63.5	60.7	103.9	38.0	37.8	Couturier, 1938
(n = 6)	4.0	4.6	1.4	1.5	1.3	0.8	
halcanica	2115	62.4	655	105.4	37.1	38.7	this paper
(n = 8)	8.2	4.9	1.3	2.5	1.4	1.0	

Tab. 2 – Loadings of craniometrical characters of the first three Principal Components extracted from males (n = 10) and females (n = 8) of the Bulgarian chamois. Characters numbers as in tab. la.

EIGENVALUES		EIGENVECTORS 1	2	3	4	5	6	7
PC I	47.991	0.460	0.475	0.271	0.436	0.064	0.465	0.281
PC II	18.884	0.205	0.221	-0.491	-0.280	-0.600	0.275	-0.391
PC III	12.744	-0.213	-0.085	0.536	0.319	0.658	-0.262	-0.236
Cumulative	79.619							

Tab. 3 – Loadings of craniometrical characters of the first three Principal Components extracted from four populations of male and three populations of female chamois. Characters numbers as in tab.1b.

		EIGENVALUES	EIGENVECTORS 1	2	3	4	5	6
MALE	I	50.970	0.500	0.334	0.397	0.486	0.307	0.387
	II	17.922	1.2E-3	-0.652	0.188	-0.253	0.672	0.153
	III	13.017	0.017	-0.298	0.687	0.236	-0.266	-0.558
FEMALE	I	49.429	0.541	0.119	0.448	0.279	0.493	0.413
	II	20.467	-0.040	-0.409	-0.141	-0.700	0.239	0.513
	III	16.782	0.018	0.843	-0.430	-0.213	0.106	0.216

then applied to allow the visualization of the discrimination among a-priori determined groups, maximizing the between-group versus the within-group variance (Camussi et al., 1991).

RESULTS

Mean values of the seven skull characters of the Bulgarian population for both sexes are shown in Tab. la. Mean values of the six skull characters of the different chamois populations are shown in Tab. 1b. Population means of total length of the skull in different populations of chamois males are shown in Fig. 1.

Sexual dimorphism is found for most of the characters, all measures (except vertical eye diameter and width at the fronto-parietal suture) being significantly larger in males. Principal Component plot generated from skull characters of the Bulgarian sample is shown in Fig. 2. About 79% of the total variability is explained by the three principal components (Tab. 2). Loadings of the first PC (PC-I) have the same sign, indicating that this component may be interpreted as representing a general size variation (e.g. McGillivary, 1985), mostly related to the lengths and maximum width of the skull. Shape differences expressed through inverse covariation between lengths and widths of the skull come out from the eigenvectors plot on PC-II and PC-III. Results from Discriminant Analysis on the Bulgarian sample show a 100% correct classification of males and one female misclassified as male. The maximum width of the skull has the highest coefficient on the discriminant function (Tab. la). As sexual dimorphism was found, further analyses were carried out separately for each sex.

Results from **PCA** computed on six craniometrical characters of specimens from different geographic origin show that the first three principal components explain **81.9%** and **86.7%** of the total variability in males and females respectively (Tab. 3). On **PC-I** the characters showing the highest weight is the total lenght the skull in males and females. Different loadings in value and sign occurr simultaneously in the second and third components. This suggests that shape dependent changes are also included in the pattern of variation. PC-II describes the variability of the nasals length in both sexes and of the maximum width of the skull in females, while PC-III **is** dominated by the maximum width of the skull in both sexes. The plots of individuals onto PCs (Fig. 3 and Fig. 4) show an

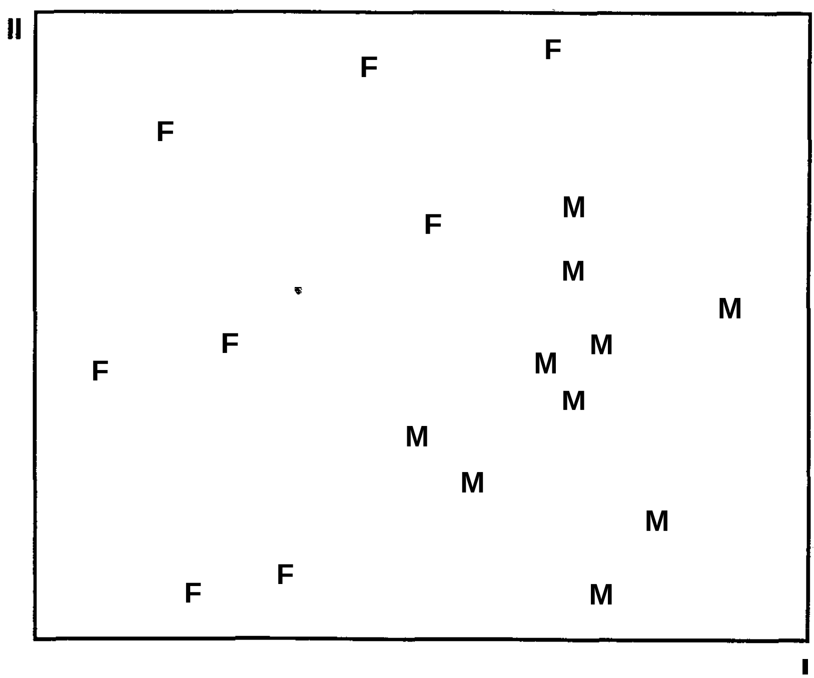

Fig. 2 – Ordination of male (M) and female (F) chamois from Bulgaria on the first two principal components. PCA was performed on seven craniometrical characters.

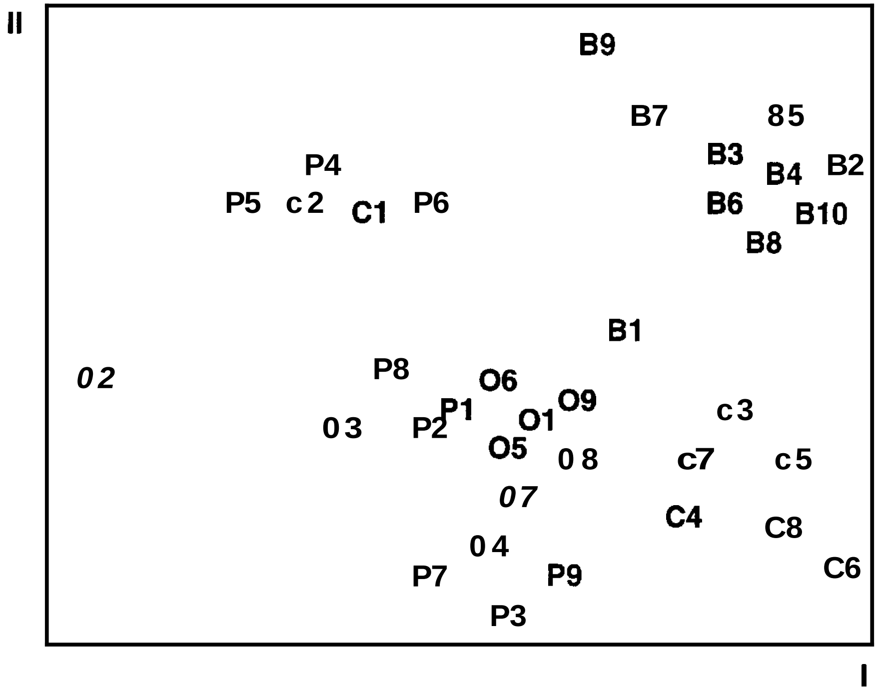

Fig. 3 – Ordination of four populations of male chamois on the first two principal components. B = *R.r. balcanica*; *C* = *R.r.* cartusiana; P = *R.p. pyrenaica;* O = *R.p. ornata.*

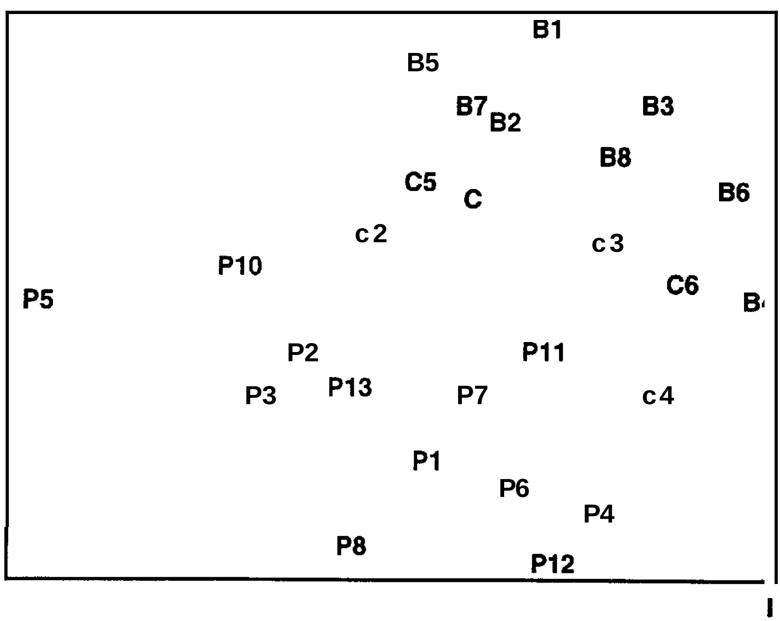

Fig. 4 – Ordination of three populations of female chamois on the first two principal components. B = *R.r. balcanica; C* = *R.r.* **cartusiana;** P = *R.p. pyrenaica*.

Tab. 4 – Standardized vector coefficients of six variables for the first three discriminant functions separating four groups (*R.r. balcanica, R.r. cartusiana, R.p. pyrenaica* and *R.p. ornata*) of male chamois and for the first two disciminant functions separating three groups of female chamois (*R.r. balcanica, R.r. cartusiana* and *R.p. pyrenaica*), according to their geographical origin.

CHARACTER	MALES			FEMALES	
	DF I	DF II	DF III	DF I	DF II
1. Total length	0.034	0.234	0.122	0.936	0.274
2. Nasals length	0.054	0.247	-0.392	-0.556	-0.373
3. Width at fronto-parietal suture	0.992	-0.574	-0.222	1.069	-0.713
4. Maximum width	-0.115	0.907	0.224	-1.054	0.716
5. Vertical eye diameter	0.331	0.580	-0.526	0.663	-0.218
6. Horizontal eye diameter	0.289	-0.432	0.960	-0.418	1.081
Eigenvalue	3.993	1.036	0.206	11.27	1.86
Relative %	76.26	19.80	3.94	85.77	14.23
Cumulative	76.26	96.06	100.00	85.77	100.00

ordination according to geographic origin. Specimens belonging to *R.r. cartusiana* males occupy an intermediate position between *R.r. balcanica* and *R. pyrenaica* spp. individuals (Fig. 3), these latter being quite scattered throughout the PC space. Females show a similar geographical trend (Fig. 4).

The first discriminant function (DF-I) derived for males (Tab. 4) separates Bulgarian chamois from those of central and western Europe and explains 76% of the total variability (Fig. 5). Classification results from DF show all *R.r. balcanica* males (except one) and all the *R.r. cartusiana* ones (except one) being correctly classified, while *R.p. pyrenaica* and *R.p. omata* males are widely crossclassified. The highest contribution to DF-I in males is given by the width at fronto-parietal suture (Tab. 4). Results from DA carried out on females show 100% correct classification. DF I, accounting for 85.8% of the total variation, separates *R.r. balcanica* from the other two populations (Fig. 6). The highest contributions to DF-I in females are given by widths and by the total length of the skull (Tab. 4). In both sexes, the highest contribution to DF-II, which accounts for 19.8% and 14.2% in males and females respectively, is given by the widths of the skull.

Figures 7 and 8 show PCA applied to the means of six characters for all the populations for males and females respectively. PC-I, that explains most of the total variability, is mainly related to the lengths , while PC-II is dominated by the nasals length in both sexes (Tab. 5). This suggest that in chamois most of the variation can be attributed mainly to a "size" factor though a "shape" factor also plays a role.

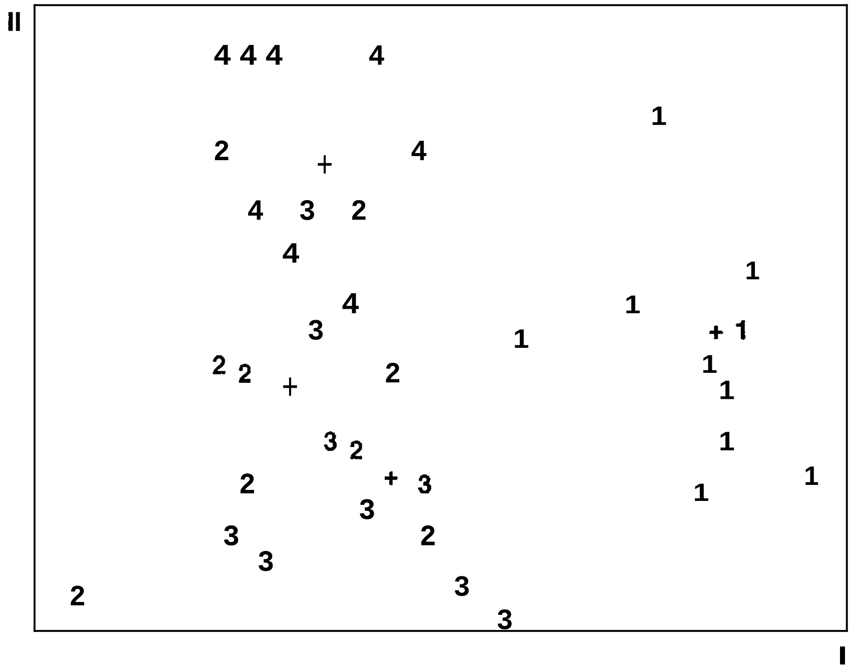

Fig. *5* – Two-dimensional plot group centroids of males of chamois populations onto the first two disciminant functions. 1=*R.r. bakanica; 2=R.p. omata; 3=R.p. pyrenaica;* 4=*R.r. cartusiana*.

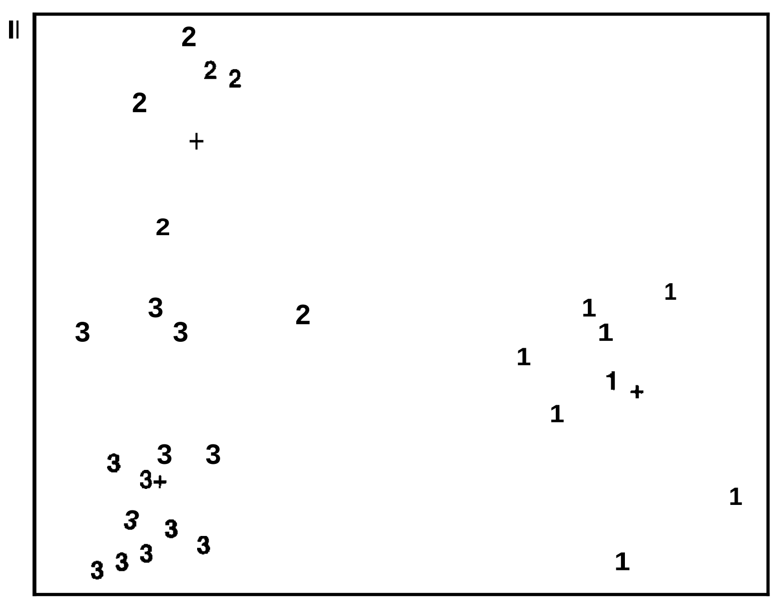

Fig. 6 – Two-dimensional plot group centroids of females of chamois populations onto the first two disciminant functions. 1=*R.r. balcanica*; *2=R.p. pyrenaica; 3=R.r. cartusiana*.

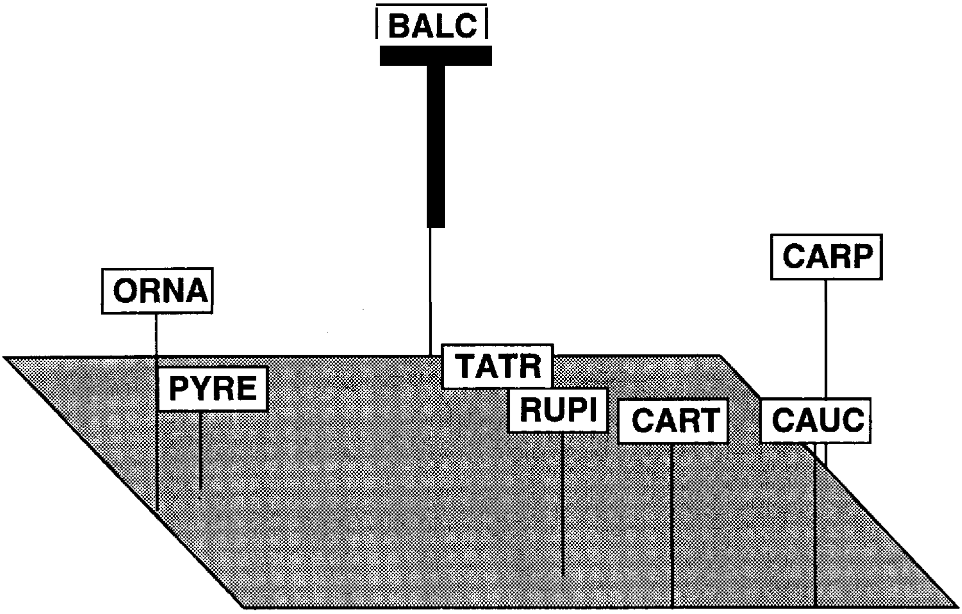

Fig. 7 – **Three-dimensional plot of PCA on average population values (males).** ORNA = *R.p. ornata*; PYRE = *R.p. pyrenaica;* CART = *R.r. cartusiana*; BALC = *R.r. balcanica*; RUPI = *R.r. rupicapra*; TATR = *R.r. tatrica;* CARP = *R.r. carpatica;* CAUC = *R.r. caucasica*.

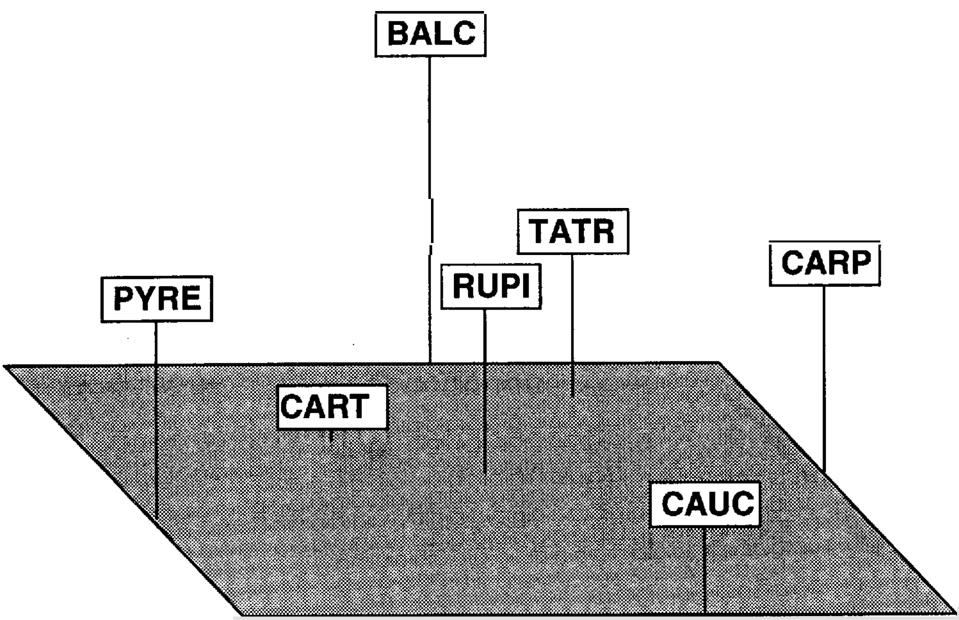

Fig. 8 – **Three-dimensional plot of PCA on average population values (females).** PYRE = *R.p. pyrenaica*; CART = *R.r. cartusiana*; BALC = *R.r. balcanica*; RUPI = *R.r. rupicapra;* TATR = *R.r. tatrica*; CARP = *R.r. carpatica*; CAUC = *R.r. caucasica*.

Tab. 5 – Loadings of craniometrical characters of the first three Principal Components extracted from eight populations of male and seven populations of female chamois. Characters numbers as in Tab. 1b. The analysis was performed on the means of the six characters.

		Eigenvalues	Eigenvectors 1	2	3	4	5	6
Male	I	66.787	0.319	0.552	0.416	0.351	0.169	0.517
	II	18.475	0.005	-0.663	0.601	0.137	0.424	-0.013
	III	9.674	0.172	0.371	0.189	0.169	0.229	-0.845
Female	I	58.187	0.439	0.325	0.430	0.375	0.370	0.488
	II	29.825	0.055	-0.882	0.204	-0.131	0.352	0.190
	III	8.107	0.062	-0.165	0.643	0.107	-0.737	-0.036

Discussion

Chamois is at present distributed over many mountain ranges of Southern Europe, the Balkan Range and the near East (Masini & Lovari, **1988)** and most of the populations are geographically isolated. Only recently groups of chamois have been introduced **for** hunting purposes to areas to which they didn't belong originally (Lovari, **1987).** In Bulgaria an introduction **of** about **30** chamois (*R.r. rupicapra*) from Austria occurred in **1977** on Rhodopes Mountains in an area not occupied by local chamois (Genov et al., **1990).**

Sexual dimorphism has been found for all the populations of chamois studied though present in different characters according to the population considered. Among the characters that usually show such dimorphism are the basal length, the nasals length and the maximum width of the **skull** (Hrabe **&** Koubek, **1982** and **1984;** Koubek **&** Hrabe **1983).** Our results confirmed this general pattern, sexual dimorphism being found for the total, condylobasal and nasals length, maximum width of the skull and width of the parieto-occipital suture. Multivariate analyses carried out on the Bulgarian sample, showed that much of the total variability is explained by a size factor associated to the total length and to the maximum width of the **skull,** though a shape factor also plays a minor role in separating sexes.

Results from DA performed on individuals belonging to different populations showed that the separation of samples conforms well to geographic origin and to the east-west axis. Results from **PCA** on both sexes indicate that morphological features characterizing chamois skull are associated both to size and shape factors. The main factor of variation among groups is a size factor expressed, in this case, through the total length of the skull. The structure of loadings on PC-II and PC-III and the amount of total variability expressed by these two components suggests also shape differences. Thus, according to multivariate analyses, *R.r. balcanica* chamois tend to separate clearly from ***R. pyrenaica*** spp. Results are consistent with the systematics of the genus ***Rupicapra*** that recognizes two species, ***R. rupicapra*** and ***R. pyrenaica*** differentiated prior the Wurm glaciation (Masini & Lovari, **1988).** ***R. pyrenaica*** split into two groups: *R.p.* ***pyrenaica*** colonised the Iberian Peninsula and the Pyrenees, *R.p. ornata* ranged from central to southern Italy. ***R. rupicapra*** spread over a wider range from the Caucasus to West Europe. This may also explain why the results of multivariate analyses show a partial overlap between *R.r. cartusiana* and *R.r. balcanica* both for males and females. The great overlap between *R.p. ornata* and ***R.p. pyrenaica*** apparently differs from the results obtained by Scala & Lovari **(1984)** on the same set of data showing the two subspecies well separated. The reason is that we excluded the naso-lacrimal fissure from analyses because of the difficulty we found in objectively measuring it, while Scala & Lovari **(1984)** underline the importance of this character in separating the two groups of chamois.

Results on the analyses performed on the means of the characters confirmed these patterns. In particular, within males *R.p.* ***pyrenaica*** and *R.p. omata* overlap almost completely thus justifying their belonging to one species.On the other hand, following a geographic criterion, *R.r. tatrica* should be closer to *R.r. carpatica* instead of being apparently more related to *R.r. balcanica* in both sexes. It is also possible that small sample size of the specimens used in this study may have partly biased the results.

On the basis of these preliminary findings, a dimensional cline for the genus *Rupicapra* (synthetised in Fig. 1) may be suggested, the north-east chamois populations showing the largest dimensions of the skulls and the south-west populations having the smallest sizes. **A** dimensional trend, following the Bergman rule, has been already found in several mammals, e.g. in wild boar (*Sus scrofa*) (Randi et al., **1989;** Genov et al., 1991), in marten (*Martes* spp.) (Reig, **1992)** and in arctic hare (*Lepus arcticus*) (Baker et al. **1978). As** multivariate analyses make no assumptions about the causes of variation, they cannot be used to separate (or to explain) ecological and genetic influences on variation. Though the effect of environment and genetics to skull variation remains an open question, the morphological differences already occurring amongst chamois populations underline the need to prevent any further introduction with specimens from different geographical area, especially in those regions, such as Bulgaria, where chamois **is** well spread.

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