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Sexual dimorphism of cranial measurements in the red fox *Vulpes vulpes* (Canidae, Carnivora) from the Czech Republic

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Abstract. For the evaluation of sexual dimorphism 739 red fox skulls (including 433 males and 306 females) from the Czech Republic were examined. The individuals younger than six months were excluded from the study of sexual dimorphism and the rest was divided into three age classes (individuals at the age of 6.5–12 months, 12.5–24 months and 24.5 months and older). Skull size differences between males and females were significant in all age classes. Males exceeded females in all dimensions with the exception of postorbital breadth, which was wider in females. Other skull shape differences between males and females were not confirmed. Age class including individuals 12.5–24 months old was the only, in which significant skull shape differences were found. We suppose that competition between males could play the major role in sexual dimorphism formation.

Key words: age class, gender differences, skull

Introduction

Sexual dimorphism in red foxes *Vulpes vulpes* (Linnaeus, 1758) has been revealed on the basis of body weight and proportions (e.g. Kolb & Hewson 1974, Lüps & Wandeler 1983, Wandeler & Lüps 1993), teeth size (e.g. Szuma 2000, Szuma 2008) and the incidence of dental anomalies (e.g. Szuma 1999, Nentvichová & Anděra 2008). Male red foxes also have longer fur than vixens (Toldt 1907–08). On the contrary, absence of any sexual variation was found by examining qualitative features, morphotypes of the teeth (Szuma 2002).

Nonetheless, differences between male and female red fox skulls are evident and have been confirmed by many authors from different regions (e.g. by Churcher 1960, Huson & Page 1979, Lüps & Wandeler 1983, Fairly & Bruton 1984, Hell et al. 1989, Ansorge 1994, Lynch 1996).

Up to now published observations from the Czech Republic are absent. Sexual dimorphism in red foxes was described in a MSc thesis by Sedláčková (Sedláčková 2005) and the skulls examined in her study are included in the present study. In additon to sexual dimorphism in skull size, the present study deals with sexual dimorphism in skull shape at different ages.

Material and Methods

The sample of 739 skulls of red fox included 433 males and 306 females. The skulls came from collections of the Department of Zoology, National Museum in Prague (440 specimens – 263 M/ 177 F), from the Institute of Vertebrate Biology of the Czech Academy of Sciences in Brno (265 specimens – 154 M/ 111 F) and from museums in Plzeň (6 specimens – 2 M/ 4 F), Opava (13 specimens – 6 M/ 7 F), Kašperské Hory (12 specimens – 6 M/ 6 F), and Frýdek-Místek (3 specimens – 2 M/ 1 F). The skulls were collected between 1957 and 2008.

The skulls were measured with a digital sliding calliper rule to the nearest 0.1 mm. The measured parameters were as follows (Fig. 1 a–d):
LCr – total length: *akrokranion – prosthion*
LCB – condylobasal length:
posterior margin of *condyli occipitales – prosthion*
LSp – splanchnocranium length:
prosthion – staphylion
LNe – neurocranium length: *staphylion – basion*
LNm – medial length of nasal bones:
sutura internasalis length
LFoI – length of *foramen incisivi*
L C-M^2 – length of upper tooth row:
alveolar distance C-M^2
L P^1-M^2 – length of upper cheek tooth row:
alveolar distance P^1-M^2
ACr+ – skull height (including sagittal crest):
base of *os occipitale* – highest point of *crista sagittalis*
LaJ – jugular breadth:
processus jugularis – processus jugularis
LaN – neurocranium breadth: *otion – otion*
LaZ – zygomatic breadth: *zygion – zygion*
LaPO – postorbital breadth:
smallest distance behind the *processi supraorbitalia*
LaI – interorbital breadth: *entorbitale – entorbitale*
LaIF – infraorbital breadth:
shortest distance between *foramina infraorbitalia*
LaR – rostrum breadth:
distance over the canine alveoles
LMd – mandible length:
infradentale – processus condyloideus
AMd – mandible height: *coronion – processus angularis*
L C-M_3 – length of lower tooth row:
alveolar distance C-M_3
L P_1-M_3 – length of lower cheek tooth row:
alveolar distance P_1-M_3

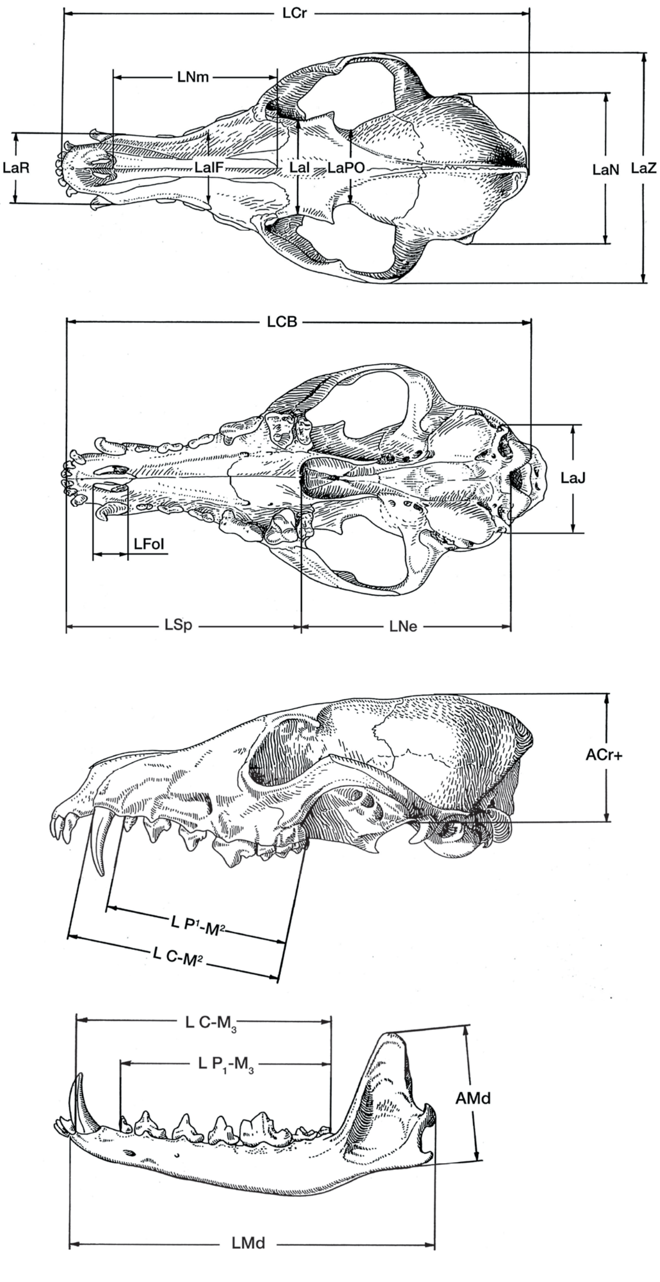

Fig. 1a–d. *Skull measurements description.*

The age was assessed to within an accuracy of two weeks (the age determination was based on the known date of death of each specimen and the date of birth, which was considered to be 1st April for all specimens. The detailed method description and explanation is in Roulichová & Anděra (2007). The most crucial procedure for age determination was counting cementum layers on longitudinally sanded canine roots. The degree of fusion of cranial sutures, clothing of the tooth pulp, and the wear of the occlusal surface of M^1 were used as additional methods of age determination.

To avoid misleading results we had to exclude the effect of age by dividing the individuals into age classes and treat them separately. The age classes were defined as follows: 6.5–12 months (242 M/ 154 F); 12.5–24 months (119 M/ 97 F) and 24.5 months and older (72 M/ 55 F). The reason for this choice was that the length parameters of the red fox skull reaches its almost full size after 6 months but the width dimensions increase significantly until the second year of life (Ansorge 1994).

All statistical analyses were processed using the program Statistica 8.0. For the overall survey of the skull parameters, the descriptive statistics were counted for each sex separately – the mean (written Mean in figures), the range (Min and Max), the standard deviation (SD) and the coefficient of variation (CV), followed by the percentage (% Diff) value of differences among means of the particular variable in males and females.

The t-test was used to reveal if the difference between particular cranial measurements of male and female red foxes were significant. All data were log-transformed (Napierian logarithm) to gain normal distribution. The probability level for decision about statistical significance was $\alpha = 0.05$.

Sexual dimorphism in various age classes was also tested with multivariate analyses. The discriminant analysis (DA) was used to find out if any two groups of individuals of different sex and age are different and which variable(s) discriminates them the best (Zima et al. 2004). The Napierian logarithms of all the data was used in multivariate analyses as well. The probability level for decision on the statistical significance of the Mahalanobis distances of the particular groups had to be reduced from 0.05 to 0.05/15 for comparisons of 6 groups (males and females in 3 age classes, we made 15 comparisons). The probability level was then $\alpha' = 0.0033$.

Principal component analysis (PCA) was used for the "size correction" to help us to reveal differences between sexes in various age groups independently of size, i.e. to find out if there are differences in shape of skulls among the particular groups. The first principal component was removed from the correlation matrix (because it was size related) and all the other factor scores were used for further analyses (DA). However, this requires that all the "loadings" (correlations of the first principal component and the variables) must have the same sign and have more or less the same value. Comparison of the two outputs – with so called size-in data and with so called size-out data, i.e. before and after the removal of the vector of size (the first principal component) from the matrix – can help us to find if the differences between sexes are dependent on size only or if there is a variation in the skull shape as well.

The tables include the value of Wilk´s λ, which is a criterion for the statistical significance evaluation. If Wilk´s $\lambda \approx 1$, the particular variable has a low prediction function, conversely, if Wilk´s $\lambda \approx 0$, the variable has high prediction significance. F is the value of the F-test, which indicates the statistical significance of Wilk´s λ. Wilk´s λ is statistically significant and the particular variable is important if the p – level is lower than 0.05 (Meloun & Militký 2004). The first Principal Component (PC1) column shows loadings, i.e. correlations of the variables with the first principal component. Other tables include the probability level counted for Mahalanobis distances and the success of DA in discriminating the individuals to particular groups expressed as a percentage of correctly discriminated individuals. Finally, the classification diagrams (diagrams of canonical scores) show the results of DA. Graphs for the first two discrimination functions are displayed. Two graphs of canonical scores were made – one for size-in data and the other after the size correction (size-out data). Nonetheless, for better lucidity each of them was displayed three times – each time for a different age class while the scores of individuals from the other age classes were erased.

Results

Descriptive statistics and t-tests

Sexual dimorphism in red fox skull size is evident already at the age of 6.5 to 12 months. The differences are statistically significant in all variables except the postorbital breadth (Table 1). The mean value of postorbital breadth in females is slightly greater than the mean value in males (Table 2). All the other dimensions in male red foxes exceed those in female red foxes. The greatest variation was connected with length dimensions (total length, medial length of nasal bones, length of *foramen incisivi* and mandible length). The least evident differences were found in the skull height and jugular breadth, which were only slightly larger in males.

Similar results were obtained when examining foxes in their second year of life, i.e. individuals between the age of 12.5 months and 24 months. Nonetheless, all the measured dimensions are greater in males, including postorbital breadth, which is only 0.3% greater in males than in females (Table 3). At the same time, postorbital breadth is the only parameter in which the statistics did not show a significant difference between males and females (Table 1).

Significant sexual dimorphism developed in individuals older than two years, too (Table 4). In the oldest age class, the greatest differences were found in the total length of the skull, in the length of splanchnocranium, the medial length of the nasal bones, the mandible length, lengths of the upper and lower tooth rows including canines, and also in the infraorbital breadth. On the contrary, the length of both the upper and lower cheek tooth rows from the first premolar were very similar in males and females. Nevertheless, all the differences in means of the variables were statistically significant, even the variation in postorbital breadth (Table 1). In summary, sexual dimorphism could be observed in all age classes in length parameters (e.g. in condylobasal length, Fig. 2), as well as in width dimension (e.g. in zygomatic width, Fig. 3). Males exceeded females

Table 1. *T-tests for individuals aged 6.5–12, 12.5 to 24 months and 24.5 months and older.*

	6.5–12			12.5–24			24.5–		
	t-value	df	p	t-value	df	p	t-value	df	p
LCr	9.05	390	0.00	7.57	214	0.00	8.08	122	0.00
LCB	8.43	384	0.00	7.27	214	0.00	7.72	120	0.00
LSp	7.01	392	0.00	5.45	214	0.00	5.76	125	0.00
LNe	8.26	384	0.00	6.94	213	0.00	7.79	120	0.00
LNm	6.06	383	0.00	6.12	212	0.00	5.56	123	0.00
LFoI	3.81	387	0.00	2.29	214	0.02	3.55	124	0.00
L C-M^2	7.52	391	0.00	5.93	214	0.00	6.40	124	0.00
L P^1-M^2	6.49	391	0.00	5.33	212	0.00	6.39	123	0.00
ACr+	3.17	385	0.00	2.74	214	0.01	3.62	119	0.00
LaJ	3.64	376	0.00	4.16	211	0.00	4.75	118	0.00
LaN	8.05	389	0.00	7.47	211	0.00	7.03	121	0.00
LaZ	8.08	381	0.00	10.14	211	0.00	6.37	124	0.00
LaPO	-1.64	390	0.10	0.37	214	0.71	-2.46	123	0.02
LaI	3.97	391	0.00	6.63	213	0.00	3.81	124	0.00
LaIF	3.71	390	0.00	2.66	213	0.01	3.47	125	0.00
LaR	6.27	389	0.00	6.94	213	0.00	4.69	124	0.00
LMd	9.21	391	0.00	7.63	214	0.00	7.33	124	0.00
AMd	6.88	393	0.00	7.10	212	0.00	6.13	125	0.00
L C-M_3	7.64	389	0.00	6.58	211	0.00	5.96	116	0.00
L P_1-M_3	7.21	388	0.00	4.72	206	0.00	4.98	108	0.00

t-value, value of the tested statistics; df, degrees of freedom; p, probability level.

Table 2. *Descriptive statistics, individuals aged 6.5 to 12 months.*

	Male 6.5–12							Female 6.5–12				
	Mean	Min	Max	SD	CV	Diff %		Mean	Min	Max	SD	CV
LCr	148.5	133.5	166.5	6.0	4.0	>	3.9	142.9	126.4	159.2	6.0	4.2
LCB	142.1	124.8	157.9	5.7	4.0	>	3.6	137.3	123.0	150.9	5.3	3.8
LSp	75.8	65.3	86.2	3.5	4.7	>	3.4	73.3	63.8	83.9	3.2	4.3
LNe	60.2	52.0	67.5	2.5	4.1	>	3.8	58.0	51.6	65.5	2.6	4.5
LNm	53.7	44.9	62.1	3.4	6.3	>	4.1	51.6	43.5	62.1	3.2	6.3
LFoI	10.1	7.2	13.0	1.0	10.1	>	4.1	9.7	6.6	12.8	1.0	10.5
L C-M^2	64.5	56.1	70.9	2.9	4.5	>	3.4	62.4	55.6	69.5	2.4	3.9
L P^1-M^2	53.6	46.4	59.5	2.4	4.5	>	3.0	52.1	45.8	58.4	2.2	4.2
ACr+	42.8	37.4	48.5	2.4	5.5	>	1.9	42.0	37.2	47.7	2.5	5.9
LaJ	36.4	32.5	40.3	1.5	4.2	>	1.6	35.8	31.1	40.2	1.6	4.5
LaN	48.4	44.2	52.3	1.5	3.2	>	2.8	47.1	42.7	51.3	1.6	3.4
LaZ	77.5	68.1	87.1	3.5	4.6	>	3.8	74.7	67.0	81.7	3.0	4.0
LaPO	22.5	18.8	27.8	1.5	6.6	<	1.2	22.7	19.2	26.6	1.6	6.8
LaI	28.0	22.5	33.5	1.8	6.3	>	2.8	27.3	21.1	57.1	3.1	11.3
LaIF	31.7	26.0	37.5	2.3	7.2	>	2.8	30.8	25.7	37.4	2.3	7.5
LaR	24.2	21.0	28.3	1.2	5.2	>	3.5	23.3	19.7	27.5	1.3	5.6
LMd	109.3	97.5	121.3	4.6	4.2	>	4.1	105.1	93.3	116.3	4.2	4.0
AMd	38.7	32.2	44.5	2.1	5.3	>	3.9	37.2	29.8	41.6	1.9	5.2
L C-M_3	72.2	63.1	80.4	2.9	4.0	>	3.2	70.0	62.4	78.0	2.7	3.9
L P_1-M_3	59.5	52.9	65.0	2.3	3.8	>	2.9	57.8	52.2	64.2	2.2	3.9

Mean (Min, Max), the average (minimum, maximum) value of the particular variable; SD, standard deviation; CV, coefficient of variation; Diff %, differences between means of the particular variables in males and females expressed in %.

Table 3. *Descriptive statistics, individuals aged 12.5 to 24 months.*

	Male 12.5–24							Female 12.5–24				
	Mean	Min	Max	SD	CV	Diff %		Mean	Min	Max	SD	CV
LCr	149.7	131.2	163.2	6.0	4.0	>	4.3	143.6	128.4	156.0	5.9	4.1
LCB	143.2	126.8	155.6	5.6	3.9	>	3.9	137.8	124.2	149.8	5.2	3.8
LSp	76.4	65.9	84.5	3.6	4.7	>	3.6	73.8	65.1	81.9	3.5	4.7
LNe	60.5	53.8	68.2	2.7	4.4	>	4.2	58.1	51.2	64.4	2.5	4.3
LNm	54.8	42.4	64.9	3.9	7.1	>	5.8	51.8	45.0	60.0	2.9	5.6
LFoI	10.0	7.7	13.1	1.1	10.8	>	3.5	9.7	6.9	12.5	1.2	11.9
L C-M^2	64.9	55.6	70.1	2.8	4.3	>	3.6	62.6	55.6	69.5	2.8	4.5
L P^1-M^2	53.7	46.0	65.8	2.5	4.6	>	3.5	51.8	43.8	57.5	2.5	4.9
ACr+	43.0	38.2	49.2	2.6	6.1	>	2.3	42.1	36.8	47.5	2.5	5.9
LaJ	36.8	32.8	40.6	1.7	4.5	>	2.5	35.9	31.8	39.6	1.4	3.9
LaN	48.8	43.7	52.5	1.6	3.4	>	3.5	47.2	42.6	50.9	1.5	3.3
LaZ	80.7	71.2	88.8	3.2	4.0	>	5.7	76.4	68.2	83.1	2.9	3.9
LaPO	22.6	18.2	26.2	1.5	6.5	>	0.3	22.5	19.5	26.5	1.4	6.3
LaI	29.4	24.0	33.8	2.0	6.6	>	5.9	27.8	23.0	32.7	1.6	5.6
LaIF	32.0	26.7	37.1	2.4	7.4	>	2.7	31.1	26.5	37.3	2.2	7.0
LaR	25.0	19.7	27.9	1.3	5.2	>	5.0	23.8	21.4	27.0	1.2	5.0
LMd	110.6	96.2	119.2	4.4	4.0	>	4.3	106.0	96.0	116.1	4.3	4.1
AMd	39.2	34.2	44.0	2.1	5.3	>	5.4	37.2	31.0	41.5	2.0	5.5
L C-M_3	73.2	63.3	79.2	2.9	3.9	>	3.7	70.6	63.6	77.7	2.8	4.0
L P_1-M_3	59.7	51.3	73.6	2.5	4.3	>	2.8	58.0	50.9	70.0	2.5	4.3

Mean (Min, Max), the average (minimum, maximum) value of the particular variable; SD, standard deviation; CV, coefficient of variation; Diff %, differences between means of the particular variables in males and females expressed in %.

Table 4. *Descriptive statistics, individuals aged 24.5 months and older.*

	Male 24.5–							Female 24.5–				
	Mean	Min	Max	SD	CV	Diff %		Mean	Min	Max	SD	CV
LCr	150.5	137.6	163.3	5.9	3.9	>	5.7	142.4	128.8	154.1	5.1	3.6
LCB	143.8	132.3	153.9	5.3	3.7	>	1.1	136.7	125.0	145.2	4.6	3.4
LSp	76.5	67.4	83.4	3.5	4.6	>	4.8	73.1	65.4	78.0	3.1	4.3
LNe	61.0	54.2	66.7	2.5	4.1	>	1.1	57.8	54.3	61.8	1.9	3.3
LNm	53.8	47.5	61.1	3.2	6.0	>	5.8	50.8	45.5	55.5	2.5	4.9
LFoI	10.1	7.7	12.7	1.0	9.5	>	1.1	9.5	7.7	11.9	1.0	10.3
L C-M^2	65.4	59.3	71.0	2.5	3.8	>	4.3	62.7	57.7	66.5	2.1	3.4
L P^1-M^2	53.9	47.6	58.7	2.0	3.7	>	1.0	51.6	46.9	54.8	1.9	3.8
ACr+	43.1	38.7	48.2	2.4	5.5	>	3.7	41.6	37.4	46.9	2.3	5.5
LaJ	37.2	34.1	40.2	1.5	4.0	>	1.0	35.9	33.1	39.1	1.5	4.2
LaN	49.0	45.8	52.2	1.5	3.1	>	4.0	47.1	43.2	51.7	1.4	3.0
LaZ	81.6	72.6	89.0	3.5	4.3	>	1.0	77.9	72.6	86.9	2.8	3.6
LaPO	22.4	19.7	26.0	1.4	6.1	<	2.8	23.0	19.6	26.9	1.5	6.5
LaI	30.0	26.2	35.0	1.9	6.5	>	1.0	28.8	25.8	34.4	1.6	5.6
LaIF	32.2	28.3	37.4	2.2	6.8	>	4.2	31.0	26.3	35.4	1.9	6.2
LaR	25.4	22.0	28.7	1.5	6.1	>	1.0	24.2	21.3	27.3	1.3	5.2
LMd	111.3	100.1	121.7	4.6	4.2	>	5.3	105.7	95.9	111.5	3.7	3.5
AMd	39.6	34.9	45.4	2.2	5.6	>	1.1	37.2	33.2	42.9	2.0	5.3
L C-M_3	73.5	67.2	80.3	3.0	4.1	>	4.5	70.3	63.5	74.3	2.6	3.8
L P_1-M_3	59.5	53.4	65.0	2.4	4.1	>	1.0	57.3	52.8	60.4	2.0	3.5

Mean (Min, Max), the average (minimum, maximum) value of the particular variable; SD, standard deviation; CV, coefficient of variation; Diff %, differences between means of the particular variables in males and females expressed in %.

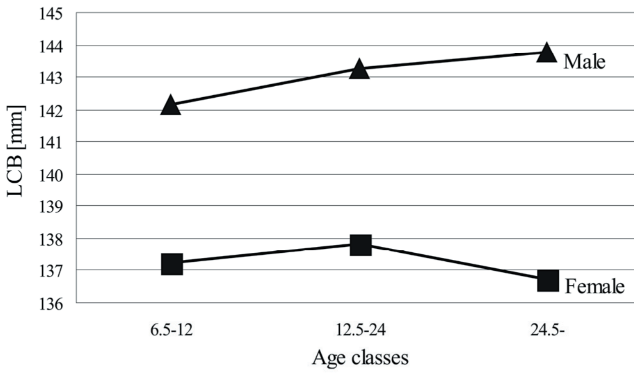

Fig. 2. *Sexual dimorphism in condylobasal length in particular age classes.*

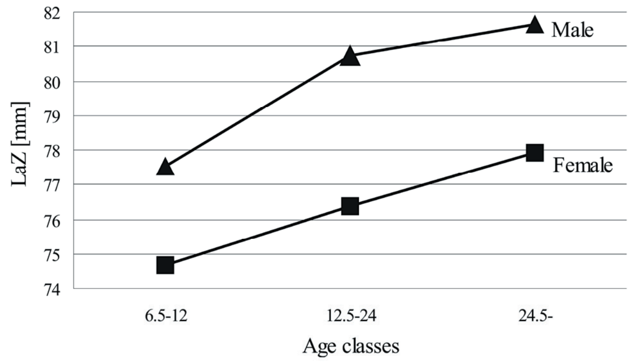

Fig. 3. *Sexual dimorphism in zygomatic breadth in particular age classes.*

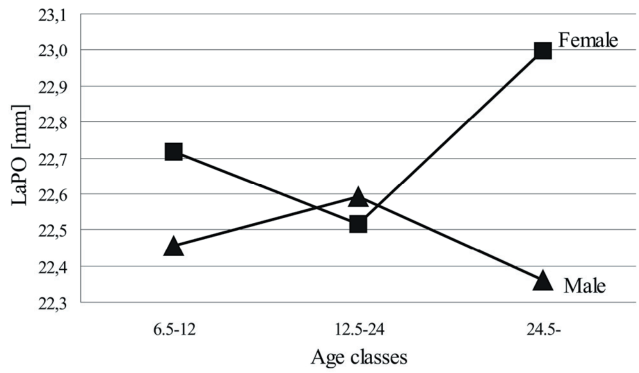

Fig. 4. *Sexual dimorphism in postorbital breadth in particular age classes.*

in all dimensions. An opposite phenomenon was observed in the postorbital breadth (Fig. 4), which is the only parameter larger in females, except individuals 12.5–24 months old.

Multivariate statistics

Fourteen out of twenty measurements were important for discriminating of males and females of different age (Table 5). Those were parameters associated with

Table 5. *Results of discrimination analysis (DA) and principal component analysis (PCA).*

	DA - size-in			PCA
	Wilk´s λ	F	p	PC1
LCr	0.42	1.46	0.20	-0.96
LCB	0.42	0.47	0.80	-0.97
LSp	0.43	3.28	0.01	-0.91
LNe	0.42	1.11	0.35	-0.80
LNm	0.43	3.75	0.00	-0.77
LFoI	0.42	0.96	0.44	-0.45
L C-M^2	0.43	3.91	0.00	-0.90
L P^1-M^2	0.42	1.59	0.16	-0.81
ACr+	0.42	2.73	0.02	-0.40
LaJ	0.43	4.44	0.00	-0.69
LaN	0.43	3.92	0.00	-0.81
LaZ	0.47	18.41	0.00	-0.76
LaPO	0.43	5.42	0.00	0.03
LaI	0.43	4.11	0.00	-0.58
LaIF	0.43	2.95	0.01	-0.57
LaR	0.42	2.80	0.02	-0.70
LMd	0.42	1.29	0.26	-0.96
AMd	0.43	3.32	0.01	-0.75
L C-M_3	0.42	2.61	0.02	-0.90
L P_1-M_3	0.42	2.46	0.03	-0.83

Wilk´s λ, criterion for the statistical significance evaluation; F, value of F-test; p, probability level; PC1, loadings – correlations of variables with the first principal component.

skull length (splanchnocranium length, length of nasal bones, length of upper tooth row from canine, and length of lower cheek tooth row from canine as well as from the first premolar), skull and mandible height and also width dimensions (jugular, neurocranium, zygomatic, postorbital, interorbital, infraorbital and rostrum breadth). The remaining variables (total length, condylobasal length, neurocranium length, length of *foramen incisivi*, length of upper cheek tooth row from the first premolar, and mandible length) were not statistically significant in the discrimination process. The first principal component was best correlated with the condylobasal length, the total length of the skull and with mandible length. It was considered to be a vector of size. The correlation value of postorbital breadth had a different sign from the other variables in PC1 and was thus not included in the size-out statistics.

Probability levels counted for Mahalanobis distances were all statistically significant in size-in statistical analysis (before size correction, Table 6), which indicates that DA (as well as the t-tests) showed significant differences between males and females from

Table 6. *Results of discrimination analysis (DA).*

	Mahalanobis distances		Discrimination – % correct	
	p – size-in	p – size-out	size-in	size-out
M_6.5–12	0.0000	0.0042	64.9	71.1
F_6.5–12			53.9	27.3
M_12.5–24	0.0000	0.0005	45.4	30.3
F_12.5–24			17.5	13.4
M_24.5–	0.0000	0.2556	34.7	23.6
F_24.5–			40.0	23.6
Total	/	/	48.4	39.6

p, probability level for Mahalanobis distances before (size-in) and after (size-out) the size correction (the distance is statistically significant if the p-level is lower than 0.0033); discrimination – % correct, the share of individuals correctly distributed in groups by DA before (size-in) and after (size-out) size correction.

all age classes. Unlike in size-out statistical analysis (after size correction), males and females in particular age classes seem to be much more similar to each other. The only significant difference in male and female skull shape was confirmed in individuals 12.5 to 24 months old. The highest level of uniqueness in size-in DA was found in males and females 6.5 to 12 months old, where DA discriminated correctly 64.9% of males and 53.9% of females. In size-out DA in males in the same age class 71.1% were discriminated correctly. The overall ratio of correctly discriminated individuals is higher when considering skull size (48.4%) than when only the skull shape is studied (39.6%).

Graphs of canonical scores (Figs. 5 to 10) show distances between individuals in multidimensional space. Each point (canonical score) displays one individual. The more close the points are, the more morphologically similar are the individulas to each other according to DA. Conversely, if the individuals (points in the graphs) form two separate groups, their morphological diversity is evident. The statistical significance of these phenomenons is proved by the probability levels counted for Mahalanobis distances. Males at the age of 6.5–12 months concentrate more on the right side of the graph, while females on the left (Fig. 5). Their morphological difference was proved statistically. On the other hand, if we consider only shape diversity, their difference is not statistically significant. Points representing individuals are much more intermixed in the size-out diagrams (Fig. 6). If we evaluate male and female skull size similarity in the older age classes, graphs of canonical scores give similar results as in younger age. Males form the right side of the graphs and females the left. Actually, the separation of points that represent males and females is much more obvious with aging (Fig. 7, 9). Differences between individuals of the age class

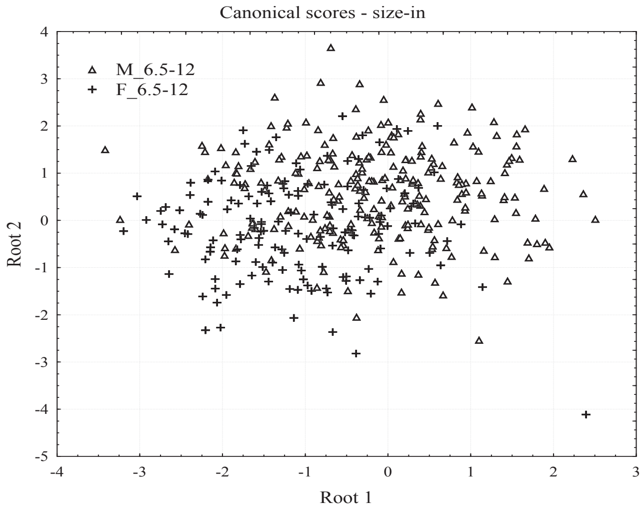

Fig. 5. *Canonical scores (first two discrimination functions). Males and females 6.5 to 12 months old before size correction.*

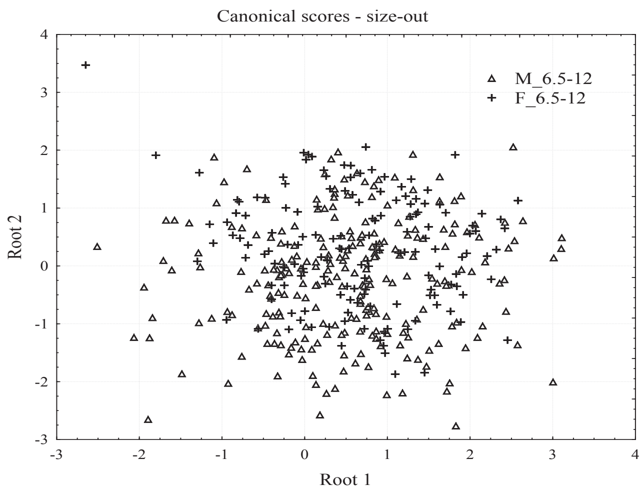

Fig. 6. *Canonical scores (first two discrimination functions). Males and females 6.5 to 12 months old after size correction.*

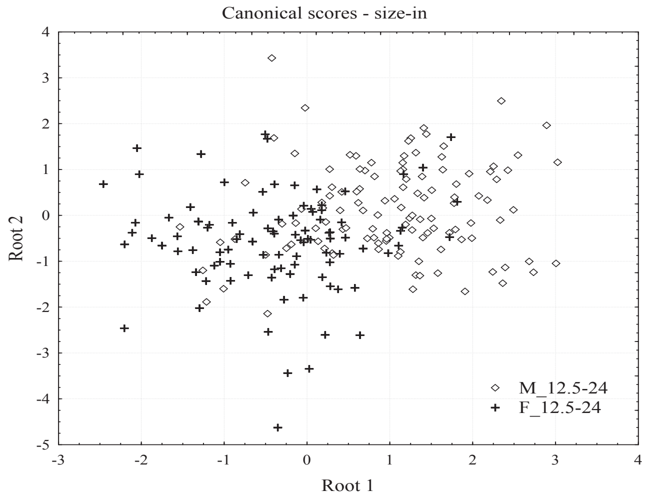

Fig. 7. *Canonical scores (first two discrimination functions). Males and females 12.5 to 24 months old before size correction.*

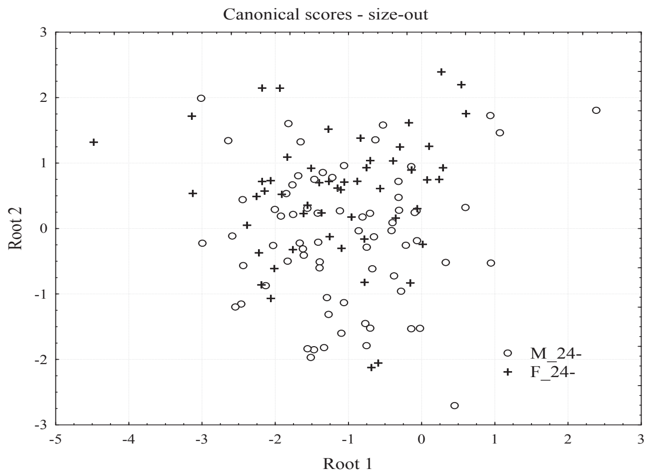

Fig. 10. *Canonical scores (first two discrimination functions). Males and females older than 24 months after size correction.*

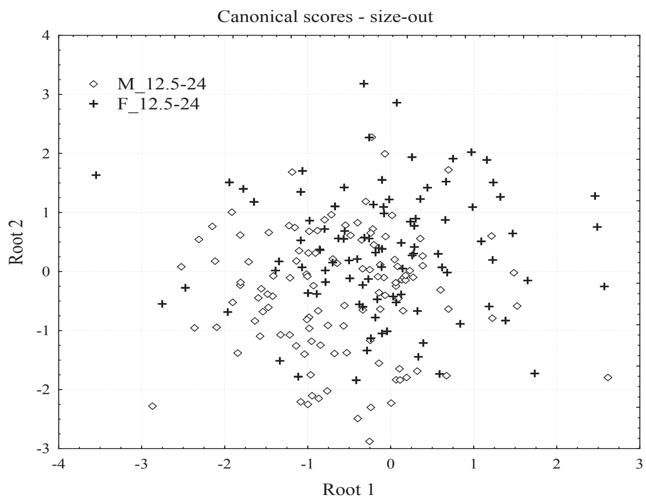

Fig. 8. *Canonical scores (first two discrimination functions). Males and females 12.5 to 24 months old after size correction.*

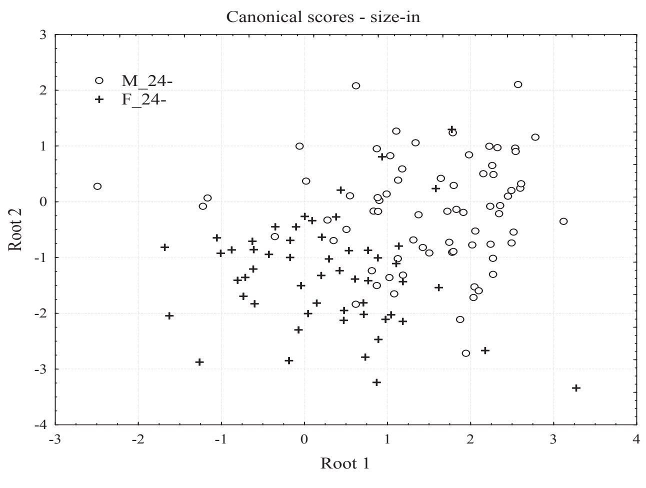

Fig. 9. *Canonical scores (first two discrimination functions). Males and females older than 24 months before size correction.*

12.5 to 24 months are apparent in skull shape as well (Fig. 8), even though the size variation is still much more obvious than the shape variation. Males and females of the oldest age class are similar considering skull shape (Fig. 10). Thus, disregarding skull size and postorbital breadth, males and females are very similar, with the only exception of individuals at the age of 12.5 to 24 months old.

Discussion

Significant distinction between red fox males and females in all skull dimensions is obvious in all age classes. The ratio of means of particular variables between males and females reflects the typical skull size and shape differences described by most authors (e.g. Hell et al. 1989, Ansorge 1994, Lynch 1996) – i.e. that male foxes have relatively longer skulls but with relatively (and in youngest and oldest age classes also absolutely) narrower postorbital breadth. The larger postorbital constriction in females was also confirmed by Fairley & Bruton (1984) in a series of skulls from Ireland, by Huson & Page (1979) who examined skulls originating from England and Wales, and also by Sedláčková (2005) dealing with skulls from the Czech Republic. The relatively narrower postorbital breadth has also been found in Eurasian badgers *Meles* spp. by Abramov & Puzachenko (2005). Conversely, Lüps & Wandeler (1983) did not find any variation in the ratio of length to width between sexes. Hence the divergence in shape cannot thus be confirmed on the basis of their research carried out in Switzerland.

According to Ansorge (1994) the narrower postorbital breadth is one of the adaptations for compensating the smaller area for *masseter* muscle insertion. It is also compensated for by a bigger sagittal crest (and consequently higher skull height with sagittal crest in male fox skulls), and also by the wider zygomatic breadth. Conversely, Churcher (1960) found no differences in the width and length of the sagittal crest between sexes in North American foxes. In the present sample, the higher skull plus sagittal crest in males was described similarly as in Ansorge´s (1994) sample and this phenomenon becomes even more distinct in older individuals. The zygomatic breadth is also significantly larger in males in all age classes.

Length of the upper and lower cheek took row measured from the first premolar is also significantly different between males and females, nevertheless, the percentage variance is small in comparison with differences in other dimensions. This phenomenon is obvious mainly in the oldest age class and could be explained by selection forces conditioning cheek teeth size. On the other hand, the length of tooth row together with canines is much longer in males. That could be connected with the longer diastema length in males and also with the greater diameter of male canines.

One could ask about the cause of sexual dimorphism. Two possible explanations are suggested – sexual selection and decrease in male-female competition (Lynch 1996). Competition between males, expressed as antagonistic behaviour and threat displays, probably played an important role in the evolution of carnivore sexual dimorphism (Meiri et al. 2005). Naturally, in the polygynous mating system, larger males are at an advantage over smaller ones, as they are more successful in reproduction (Abramov & Puzachenko 2005). Conversely, selective pressures do not give priority to larger males in monogamous species as observed e.g. in Finnish racoon dogs *Nyctereutes procyonoides*, where larger males would be handicapped because of a lack of food. And thus selection forces supported formation of an ideal body size, which is the same for males and females (Kauhala et al. 1998). Sexual size dimorphism in red fox could result in a partial separation of the food niche and might thus contribute to the elimination of intraspecific feeding competition between male and female red foxes. The narrower postorbital constriction and a longer and higher sagittal crest enlarge the area for muscle insertion and the male jaw becomes stronger. Thus, male foxes could be able to handle relatively larger prey. Trophic differentiation between males and females related to narrower postorbital constriction in males and thus also to larger anterior part of the *temporalis* muscle was confirmed in some mustelid carnivorous species e.g. in stone marten *Martes foina* by Loy et al. (2004). Nonetheless, there is no such evidence of niche separation between male and female red foxes, as stated by Lynch (1996). Similarly, Abramov & Puzachenko (2005) suggested that differences in diet between males and females were not the probable reasons for skull size sexual dimorphism in omnivorous species.

Sexual dimorphism in skull size in favour of males is thus clear and an opposite trend in the growth of postorbital breadth, e.i. that females have wider postorbital constriction, as well. On the other hand, it is not easy to reveal any other skull shape differences. No single parameter distinguishes males and females significantly. Similar results were obtained by Pankakoski & Nurmi (1986) who examined a sample of muscrat skulls. Their study also showed that no single measurement could be used for discrimination between sexes, contrary to work on the mink *Mustela vison* by e.g. Wiig & Lie (1979). When postorbital breadth was not included in statistical tests, no apparent shape differences were found between sexes, especially in individuals older than two years, where all the dimensions should be stable. The skull shape similarity was also confirmed by the share of the correctly discriminated animals in multivariate analysis. The percentage of correctly discriminated individuals was higher in size-in analyses. In size-out analyses the discrimination value was quite low, indicating that after size correction all the individuals were quite similar.

Sedláčková (2005) used a different method to reveal differences in skull shape between sexes – the cranial indexes, i.e. the ratio of two cranial measurements, that should also eliminate the influence of skull size and thus show only shape-dependent sexual dimorphism. She obtained the same results as presented here. Only the indices associated with postorbital constriction were significantly different between males and females.

These results clearly show that any further biometric analyses of population, ontogenetic, or geographic variability of the red fox will require separate evaluation for males and females.

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