ACTA SCIENTIARUM POLONORUM *Acta Sci. Pol., Zootechnica 12 (2) 2013, 15–30*

DOMESTICATION OF THE RED FOX (*VULPES VULPES*) REFLECTED IN METRIC CHARACTERS OF SELECTED THORACIC GIRDLE BONES

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Abstract. The aim of this study was to compare the characters of the pectoral girdle morphological elements between the wild and captive, farm-bred forms of the red fox. The study was conducted on the humeri, radii, ulnae, and scapulae collected from 24 wild and 20 farmed red foxes. Each individual was posthumously measured for body weight and natural length, and the bones of the anterior girdle were collected. Images of humeri and their epiphyses were used for measurements. Statistical analysis of the measurements suggests that most metric characters of the shoulder girdle bones are greater in farmed fox. Captive foxes are characterized by a larger body weight and a shorter body as compared to the wild form. There were significant ($P \leq 0.01$, $P \leq 0.05$) dimorphic differences in the length and breadth of the humeral epiphysis and radial epiphysis. Also, we found a significant ($P \leq 0.01$, $P \leq 0.05$) effect of origin on the length of the bones.

Key words: domestication, humerus, radius, red fox, scapula, ulna

INTRODUCTION

The red fox (*Vulpes vulpes*) is an European native species commonly seen in the forests and fields across the entire continent; it is also the world's most common species among terrestrial carnivores [Cavallini 1996, Cavallini, Volpi 1996, Gortázar et al. 2003, Aubry et al. 2009]. Lacking natural enemies and due to very efficient campaigns against rabies [see e.g. Vos et al. 2008], the wild populations of the red fox in Europe have grown considerably in recent years. In North

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America, deliberate introductions of farm-bred foxes to the environment, which took place in the early 20th century [Lewis et al. 1995, Statham et al. 2011], could have contributed quantitatively to wild populations. For example, foxes were released on San Juan Island (Washington, USA) in 1947, as a control measure against a plague of rabbits [Schoen 1972].

The origins of fox farming reach back to 1890 when the first farm was built in Canada [Westwood 1989]. Nowadays, it is believed that the behavior of the species after several decades in captivity has undergone profound changes, and the ability of a captive fox to survive at large are heavily impaired. As a result of farming, foxes lost their natural sense of hunting, mobility, and terrain orientation [O'Regan, Kitchener 2005]. Trut [1999], who carried out long-term on-farm observations, noted that escapees—either silver foxes or American mink—often returned to the farm after a short time. Frankham et al. [1986] found that selection of non-skittish individuals for easier adaptation to life in captivity could have reduced their chances of survival in the wild.

Many changes that mark the process of domestication are reflected in differences between the red fox undomesticated populations and those bred on farms. These changes occurred both in the external appearance—varied body sizes and diversity of colors—and inside the body, e.g. in the sizes of internal organs. Cavallini [1997], who studied wild and captive foxes, reported that the weight of the heart, liver, spleen, kidneys, and adrenal glands were more variable in wild foxes than in captive ones. Other studies have revealed significant differences in the structure of some parts of the aorta; it was longer and larger in diameter in wild foxes compared to captive ones, the latter group having a shorter descending thoracic aorta and a larger in diameter abdominal aorta [Nowicki 2005]. This variability is probably due to a greater environmental and genetic diversity of wild foxes [Cavallini 1997; Nowicki 2005].

The sizes of foxes in the wild strongly depend on their habitat and availability of food. Comparison of male wild foxes over a large area of Italy showed that individuals living in the North are larger in both weight and natural length, as compared to those captured in the South [Cavallini, 1995].

Discovering the origin of domestic species has been raising wide interest for many years [Zeuner 1963]. Domestication of herbivorous and predatory mammals caused similar changes in their appearance, size, coat color, behavior, reproduction habits, and biology [Belyaev 1979, Hare et al. 2005]. The red fox has been formally recognized as a livestock animal and its captive individuals are characterized by a higher morphological, physiological, and behavioral diversity in relation to its wild forms [Trut 1999; O'Regan, Kitchener 2005]. The altered morphological characteristics include the length and breadth of the cranium and long bones [Trut 1999]. Also, according to the same Author, the sexual dimorphism, preserved among individuals inhabiting the natural ecosystem, seems to disappear within 15 to 20 generations of farm breeding.

Changes in the appearance of captive foxes, as compared to wild ones, are primarily due to the pace of selection [O'Regan, Kitchener 2005], whereas the morphological changes represent a side effect of both behavior-motivated selection and greater availability of food [Trut 1999]. Wild populations demonstrate remarkably stable morphology, which may be illustrated by the fact that the body weight and length of the humerus of present-day red foxes are similar to those of vulpine remains recovered from the cemetery of Van-Yoncatepe in Turkey, dated back to the first millennium B.C. [Onar et al. 2005].

The aim of this study was to compare the body weight and length as well as the values of morphological traits of the bones of the pectoral girdle and the free part of the anterior limb of the red foxes; the analysis included wild and captive foxes from the southern part of Poland.

MATERIAL AND METHODS

We studied 24 wild- and 20 captive individuals of red fox (*Vulpes vulpes*). The animals came from the area located in the south of Poland, where the wild specimens had been captured using restraining traps, and the captive foxes were obtained from a fur farm. The study was conducted in compliance with the binding Polish laws, and–prior to its commencement–the project had received a relevant permission from the Local Ethics Committee (permit no. 83/2009).

The individuals of both sexes were at age of about one year; the distribution of sexes is shown in Tables 1–4.

The foxes were posthumously measured for body weight and natural length (the distance between the place where the outer edges of the anterior nares join the philtrum and the palpable space between the third sacral vertebra and the first caudal one). The following elements of the thoracic limb girdle (*cingulum membri thoracici*) were collected from all the specimens: the shoulder blade (*scapula*) and the bones of the free thoracic limb represented by the *humerus*, *radius*, and *ulna*. All the bones of each specimen were measured using a methodology borrowed from the studies of Alpak et al. [2004] and Monchot and Gendron [2010]. The measurements of the *humerus*: GL – Greatest length; GLI – Greatest length of the lateral part (from the cranial part of the lateral tuberosity to the most distal point of the lateral border of the trochlea); GLC – Greatest length from caput; BP – Greatest breadth of the proximal end; BD – Greatest breadth of the distal end; BT – Greatest breadth of the trochlea; SD – Smallest breadth of diaphysis. *Radius*: GL – Greatest length; BP – Greatest breadth of the proximal end; BD – Greatest breadth of the distal end; SD – Smallest breadth of diaphysis. *Ulna*: GL

– Greatest length; SDO – Smallest depth of the olecranon; DPA – Depth across the anconeal process. *Scapula*: LD – Greatest dorsal length; HS – Height along the spine; DHA – Diagonal height; from the most distal point of the scapula to the thoracic angle; SCL – Smallest length of the collum scapulae; GLP – Greatest length of the glenoid process.

In addition, photographs of the humeri were taken in horizontal projection of the frontal plane (parallel to the trochlea axis) and the furthest point of the caput and the proximal border of the attachment field of the flexor muscles on the medial epicondyle were marked. The MultiScan program was used to estimate the total surface area of the shaft projection. Moreover, we took vertical projection photographs of the proximal and distal epiphyses, and the surface areas of both were measured using MultiScan (the results were used to estimate the values of indices 4–7). The epicondylar-epiphyseal angle measurements were made on drawn outlines of the bones, measuring the angle between the axis of the shaft and a straight line passing through two outermost points of the distal epiphysis projection. The results were analyzed statistically using the Statistica V.9.0 PL package. The studied traits did not show normal distribution. The values of the arithmetic mean, standard deviation (SD) and coefficient of variation (V%) were estimated. The nonparametric Mann-Whitney U-test was used to determine the effect of origin and gender of the mean values in each measurement. The following indices were also calculated:

Humerus:

- Index 1 = (Breadth of proximal epiphysis) × 100/(Total length);
- Index 2 = (Breadth of distal epiphysis) × 100/(Total length);
- Index 3 = (Breadth of diaphysis) × 100/(Total length);
- Index 4 = (General massiveness) = (Total projection surface area (mm2)/ /(Greatest length);
- Index 5 = (Epiphyseal-diaphyseal index) = (Surface area of proximal and distal epiphysis projection) × 100/(surface area of diaphysis projection);
- Index 6 = (Proximal epiphyseal index) = (Surface area of proximal epiphysis projection) × 100/(Total projection surface area);
- Index 7 = (Distal epiphyseal index) = (Surface area of distal epiphysis projection) × 100/(Total projection surface area).

Radius:

- Index 8 = (Breath of proximal epiphysis) × 100/(Total length);
- Index 9 = (Breath of distal epiphysis) × 100/(Total length);
- Index 10 = (Breath of diaphysis) × 100/(Total length).

Ulna:

- Index 11 = (Depth across the anconeal process) $\times$ 100/(Total length).

Scapula:

- Index 12 = (Breadth of the dorsal edge) $\times$ 100/(External length).

We also studied the external structure of the humeral surface. Each bone was assigned to one of three following categories: strong, medium and weak. The *chi*-square test was used to evaluate the results of this analysis. We also performed an analysis of correlation between body weight of foxes and the length of the humerus. The results are shown in Tables 1–4 and Figures 1 and 2. The numbers of specimens (n) given in Tables 2 and 3 may differ between parameters, since some measurements were unfeasible due to bone damages.

RESULTS

In order to determine the effect of origin and sex on the studied traits, we used the F-test (Table 1). A significant ($P \leq 0.01$) effect of gender and origin, and non-significant origin $\times$ sex interaction were found for most of the analyzed traits. The body weight of farm foxes of either sex was 1.0–1.5 kg, on average, higher than the body weight of wild animals (Table 2). The average body weight of males and females of captive foxes was higher by 20% compared to wild foxes of the same sex. Statistical analysis of the osteological material data showed significant ($P \leq 0.01$ and $P \leq 0.05$) effect of the origin (wild vs. captive) and gender on the length (GL, GLI and GLC) and the gender on the breadth of the proximal (BP) and distal (BD) ends of the humerus. The length of the humerus of captive males and females was about 4.78 to 5.76% higher compared to that of individuals of both sexes captured in the natural environment. Humerus of captive males and females were also characterized by 5.42–6.07% greater length of the lateral part (GLI) and by about 5.5% higher length from caput (GLC). Males in each population had significantly ($P \leq 0.05$) higher value of greatest breadth of the distal end, as compared with females. There was no effect of origin and gender of foxes on the value of the greatest breadth of the humeral trochlea (BT) and the smallest breadth of the shaft of the bone (SD). A higher (statistically non-significant) value of the epicondylar-epiphyseal angle of the humerus in wild male foxes compared with females of this group and individuals from the population of captive foxes (Table 2).

Analysis of the metric characteristics of the radius showed significant ($P \leq 0.01$and $P \leq 0.05$) effect of origin and gender on the length, and gender

Table 1. Effect of origin and sex on analyzed characters of foxes – test F

Tabela 1. Wpływ pochodzenia i płci na badane cechy lisów – test F

Character – Cecha	Sex – Płeć	Origin – Pochodzenie	Interaction – Interakcja
Body weight – Masa ciała	23.31**	42.85**	2.24
Natural length – Długość naturalna	12.60**	0.00	2.73
Humerus – Kość ramienna			
GL	34.95**	21.06**	0.07
GLI	32.32**	22.92**	0.01
GLC	30.93**	21.22**	0.00
BP	9.19**	0.00	0.10
BD	11.20**	1.21	0.00
BT	3.27**	3.52**	0.00
SD	0.20	12.05**	0.04
Index 1 – Indeks 1	1.08	27.44**	0.00
Index 2 – Indeks 2	1.52	9.74**	0.14
Index 3 – Indeks 3	8.02**	35.95**	0.42
Index 4 – Indeks 4	6.69*	3.93	0.03
Index 5 – Indeks 5	0.71	0.70	0.04
Index 6 – Indeks 6	1.94	0.38	0.00
Index 7 – Indeks 7	3.34	0.12	1.62
Radius – Kość promieniowa			
GL	44.04**	22.99**	0.44
BP	11.51**	2.47	0.66
BD	17.02**	0.60	0.62
SD	1.39	32.35**	7.74**
Index 8 – Indeks 8	2.81	20.53**	0.04
Index 9 – Indeks 9	1.38	26.72**	0.00
Index 10 – Indeks 10	2.80	57.12**	4.06
Ulna – Kość łokciowa			
GL	38.64**	21.30**	0.64
DPA	9.69**	0.14	0.00
SDO	6.27*	2.26	0.16
Index 11 – Indeks 11	1.81	23.64**	1.41
Scapula – Łopatka			
LD	18.68	2.80	2.38
HS	57.65	8.62**	1.74
DHA	60.10	3.69	0.78
SCL	13.29	10.63**	0.15
GLP	33.70	2.19	0.00
Index 12 – Indeks 12	0.19	0.43	1.37

Effect of the factor significant at: (*) $P \leq 0.05$ and (**) $P \leq 0.01$.
Wpływ czynnika istotny na poziomie: (*) $P \leq 0,05$ i (**) $P \leq 0,01$.

on the breadth, of the proximal and distal parts of the bones in wild foxes. A significant effect ($P \leq 0.01$) of the origin of foxes on the breadth of the radial diaphysis was noted. The breadth of the radial diaphysis of wild-fox males was about 21.89% greater compared to the value of this trait in captive foxes. The gender was a significant ($P \leq 0.01$) source of variability in the length of the ulna of both the group caught in natural conditions and those from breeding. The origin of either a male or a female also significantly ($P \leq 0.01$, $P \leq 0.05$) affected the length of the ulna, which was longer in those obtained from breeding. Other metric traits of the ulna did not vary significantly. The measurements of the scapula revealed that gender had no significant effect on the dorsal length of the bone only in captive animals. Other metric traits of the scapula were greater in males compared to females, with no significant effect of the origin of the animal.

Table 3 shows the statistical comparison of the calculated indices for each bone. Gender influenced significantly ($P \leq 0.01$, $P \leq 0.05$) the index 1, both in wild and captive foxes, and the index 4 in captive foxes. In contrast, the origin was significant ($P \leq 0.01$, $P \leq 0.05$) source of variation for indices: 3, 8, 9, 10, and 11.

Spearman correlation coefficients were calculated for the selected metric characteristics of the scapula, humerus, radius, and ulna (Table 4). A strong and a statistically significant correlation was observed between the length of the humerus and the breadth of the proximal epiphysis, between the length and the breadth of the diaphysis of the humerus (respectively, $r = 0.86$ and $r = 0.75$), between the radial bone length and the breadth of the distal epiphysis of the radius ($r = 0.76$), and between the external length of the scapula and the breadth of the dorsal edge of the scapula ($r = 0.75$) in wild males. The values of correlation coefficients between selected metric features of the studied bones in wild female foxes and those in captive males and females indicated no correlation at all, or weak and statistically insignificant.

The correlation between the length and breadth of the humeral diaphysis is shown in Figure 1. One can see here that with increasing length of the humerus in wild foxes the breadth of the diaphysis increases too, while in captive foxes this correlation is not that strong. The breadth of the humeral diaphysis was smaller in captive animals, as compared to wild ones.

Figure 2 shows the relationship between body weight of foxes and the length of the humerus. Both traits are highly correlated with each other—Spearman's rank correlation coefficient was 0.67; the length of the humerus increased with an increase in body weight.

Analysis of the bone surface structure revealed no significant differences in the distribution of the structural details of the surface of these bones, and the chi-square test theoretical value was 2.8644.

Table 2. Metric characters of humerus and scapula of wild and captive foxes of either sex

Tabela 2. Cechy metryczne kości ramiennej i łopatki dzikich i hodowlanych lisów obojga płci

Character Cecha	Wild foxes – Lisy dzikie								Captive foxes – Lisy hodowlane							
	Males – Samce				Females – Samice				Males – Samce				Females – Samice			
	n	mean	SD	V%	n	mean	SD	V%	n	mean	SD	V%	n	mean	SD	V%
Body weight Masa ciała	15	6.05^{AB}	0.83	13.77	9	4.79^{AC}	0.42	8.8	10	7.06^{B}	0.43	6.13	10	6.39^{C}	0.66	10.36
Natural length Długość naturalna	15	66.00^{A}	3.09	4.69	9	61.89^{A}	2.42	3.91	10	64.70	2.21	3.42	10	63.20	2.10	3.32
Humerus – Kość ramienna																
GL	9	130.30^{Aa}	4.65	3.57	8	121.39^{AB}	6.21	5.12	10	136.54^{Ca}	2.30	2.54	10	128.39^{BC}	2.95	3.47
GLI	9	128.16^{Aa}	4.59	3.58	8	119.57^{AB}	6.36	5.32	10	135.11^{Ca}	3.80	2.81	10	126.83^{BC}	3.06	2.42
GLC	9	127.20^{Aa}	4.24	3.33	8	119.09^{Ab}	6.43	5.40	10	133.96^{Ba}	3.77	2.82	10	125.80^{Bb}	3.08	2.45
BP	7	18.39^{A}	0.71	3.86	7	17.28^{A}	1.00	5.78	10	18.28^{a}	0.45	2.49	10	17.38^{a}	0.42	2.43
BD	7	21.35^{a}	0.97	4.54	7	20.24^{a}	1.24	6.14	10	21.70^{b}	0.53	2.43	10	20.61^{b}	0.53	2.59
BT	7	14.30	0.71	5.00	7	13.72	0.83	6.07	10	13.70	0.40	2.89	10	13.09	0.50	3.79
SD	7	8.28	0.60	7.28	7	8.24	0.59	7.13	10	7.73	0.31	3.98	10	7.63	0.50	6.52
Epicondylar--epiphyseal angle – Kąt kłykciowo--trzonowy	7	101.24	12.26	12.11	7	95.35	9.64	11.16	10	95.96	5.91	6.16	10	94.21	5.85	6.21
Radius – Kość promieniowa																
GL	9	122.70^{Aa}	4.46	3.63	8	113.62^{AB}	5.06	4.45	10	127.84^{Ca}	3.22	2.52	10	120.41^{BC}	2.14	1.77
Bp	9	12.17^{a}	0.56	4.63	8	11.50^{a}	0.76	6.59	10	11.79	0.29	2.47	10	11.37	0.25	2.22
Bd	9	15.82^{a}	0.79	4.99	8	14.80^{a}	0.75	5.10	10	15.50	0.43	2.80	10	14.81	0.50	3.41
SD	9	8.24^{A}	0.55	6.68	8	7.55	0.37	4.96	10	6.76^{A}	0.50	7.45	10	7.04	0.63	9.01
Ulna – Kość łokciowa																
GL	10	143.13^{Aa}	4.82	3.36	8	133.00^{AB}	6.17	4.64	10	148.64^{Ca}	3.82	2.57	10	140.82^{BC}	2.60	1.84
DPA	10	15.86	1.09	6.86	8	15.15	0.58	3.83	10	15.95	0.47	2.93	10	15.23	0.44	2.86
SDO	10	13.43	0.72	5.40	8	12.95	0.78	6.05	10	13.18	0.73	5.51	10	12.52	0.53	4.26
Scapula – Łopatka																
LD	15	53.00^{A}	3.51	6.61	9	48.02^{A}	2.16	4.49	10	53.12	1.96	3.69	10	50.75	2.44	4.82
HS	15	87.26^{A}	3.03	3.47	9	80.04^{Aa}	3.48	4.35	10	88.57^{B}	1.29	1.46	10	83.49^{Ba}	1.76	2.11
DHA	15	87.05^{A}	2.86	3.29	9	79.79^{A}	3.87	4.85	10	87.92^{B}	1.29	1.47	10	82.15^{B}	1.89	2.30
SCL	15	17.05	0.97	5.48	9	16.25	1.00	6.16	10	16.35^{a}	0.57	3.51	10	15.36^{a}	0.39	2.57
GLP	15	18.82^{A}	0.51	2.70	9	17.70^{A}	1.01	5.72	10	18.53^{B}	0.35	1.87	10	17.41^{B}	0.39	2.25

Means marked with the same letters in rows differ significantly: A, B, C at $P \leq 0.01$; a, b, c at $P \leq 0.05$.
Średnie oznaczone tymi samymi literami w rzędach różnią się isotonie: A, B, C na poziomie $P \leq 0,01$; a, b, c na poziomie $P \leq 0,05$.

Table 3. Osteometric indices of selected bones of the pectoral girdle in wild and captive foxes

Tabela 3. Wskaźniki osteometryczne wybranych kości pasa piersiowego u lisów dzikich i hodowlanych

Index Wskaźnik	Wild foxes – Lisy dzikie								Captive foxes – Lisy hodowlane							
	Males – Samce				Females – Samice				Males – Samce				Females – Samice			
	n	mean średnia	SD	V%	n	mean średnia	SD	V%	n	mean średnia	SD	V%	n	mean średnia	SD	V%
Humerus – Kość ramienna																
1	9	14.11^{A}	0.28	1.98	8	14.24^{A}	0.63	4.45	10	13.39^{B}	0.38	2.83	10	13.54^{B}	0.30	2.22
2	9	16.39	0.60	3.69	8	16.68	0.72	4.35	10	15.90	0.43	2.73	10	16.05	0.38	2.34
3	9	6.35^{A}	0.33	5.16	8	6.80^{B}	0.54	7.97	10	5.66^{A}	0.21	3.66	10	5.95^{B}	0.43	7.26
4	7	13.04	1.29	9.79	7	11.25	1.82	16.22	10	11.60	1.36	11.70	10	10.93	2.15	19.71
5	7	59.41	15.80	26.58	7	72.47	17.43	24.05	10	56.81	7.53	13.26	10	69.53	20.10	28.91
6	7	23.57	5.10	21.63	7	29.53	8.02	27.17	10	22.04	3.37	15.31	10	28.30	10.86	38.38
7	7	15.35	3.10	20.22	7	20.47	4.43	21.65	10	15.17	2.33	15.38	10	16.98	3.98	23.46
Radius – Kość promieniowa																
8	9	9.88^{a}	0.43	4.40	8	10.16^{b}	0.79	7.77	10	9.22^{a}	0.26	2.80	10	9.45^{b}	0.21	2.19
9	9	12.89^{A}	0.41	3.20	8	13.07^{B}	0.62	4.77	10	12.13^{A}	0.37	3.02	10	12.30^{B}	0.40	3.24
10	9	6.72^{A}	0.35	5.17	8	6.67^{B}	0.48	7.27	10	5.29^{Aa}	0.41	7.74	10	5.85^{Ba}	0.54	9.22
Ulna – Kość łokciowa																
11	10	11.08	0.71	6.42	8	11.40^{AA}	0.45	4.00	10	10.79	0.21	2.03	10	10.81^{A}	0.20	1.89
Scapula – Łopatka																
12	15	60.71	2.82	4.65	9	60.03	2.66	4.44	10	59.98	2.49	4.16	10	60.77	2.13	3.51

Means marked with the same letters in rows differ significantly: A, B at $P \leq 0.01$; a, b at $P \leq 0.05$.
Średnie oznaczone tymi samymi literami w rzędach różnią się isotonie: A, B na poziomie $P \leq 0{,}01$; a, b na poziomie $P \leq 0{,}05$.

Table 4. Correlation coefficients of selected characters of humerus, radius, and scapula in wild and bred foxes of either sex

Tabela 4. Współczynniki korelacji dla wybranych cech kości ramieniowej, promieniowej oraz łopatki lisów dzikich i hodowlanych obojga płci

Character Cecha	Wild foxes – Lisy dzikie		Captive foxes – Lisy hodowlane	
	Males – Samce n = 9	Females – Samice n = 8	Males – Samce n = 10	Females Samice n = 10
Length of humerus – Długość kości ramiennej				
BP	0.86**	0.69	0.36	0.56
BD	0.60	0.70	0.40	0.54
SD	0.75*	0.19	0.42	–0.23
Length of radius – Długość kości promieniowej				
BP	0.42	0.13	0.34	0.42
BD	0.76*	0.51	0.35	0.36
SD	0.64	–0.19	0.03	–0.01
Length of ulna – Długość kości łokciowej				
DPA	0.37	0.57	0.74	0.68
Length of scapula, outer – Długość zewnętrzna łopatki				
HS	0.75*	0.50	–0.12	0.66

Coefficients of correlation significant at: (*) $P \leq 0.05$ and (**) $P \leq 0.01$.
Współczynniki korelacji istotne na poziomie: (*) $P \leq 0{,}05$ i (**) $P \leq 0{,}01$.

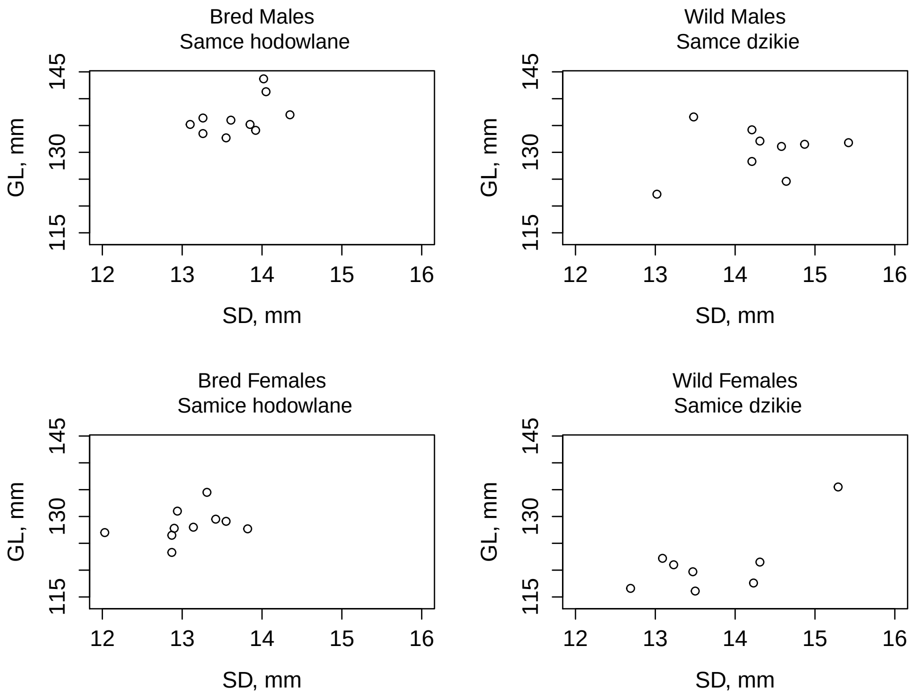

Fig. 1. Correlation between humeral greatest length and humeral smallest diaphisis breadth in wild and bred foxes of either sex

Rys. 1. Korelacja pomiędzy największą długością kości ramiennej a najmniejszą szerokością nasady kości ramiennej u dzikich i hodowlanych lisów obojga płci

DISCUSSION

The study revealed that body weight of present-day wild red foxes is very similar to that of foxes found along buried remains of man by Onar et al. [2005], dated back to the first millennium BC. The body weight of those ancient foxes ranged from 5.13 to 7.65 kg. Also the lengths of the excavated vulpine humeri were similar to that of the present-day foxes, and ranged from 115.16 to 129.0 mm, with their shafts ranging from 7.18 to 8.20 mm in breadth. Also Monchot and Gendron [2010] state that the size of the wild red foxes have not changed for two thousand years. The results of the presented study, involving wild and bred red foxes from the areas of southern Poland, confirm these reports. Our data reveal interesting levels of the coefficients of variation estimated for each group. The greatest measures of dispersion were observed in the bone specimens belonging to wild males and females, which applies to each studied bone of the pectoral girdle.

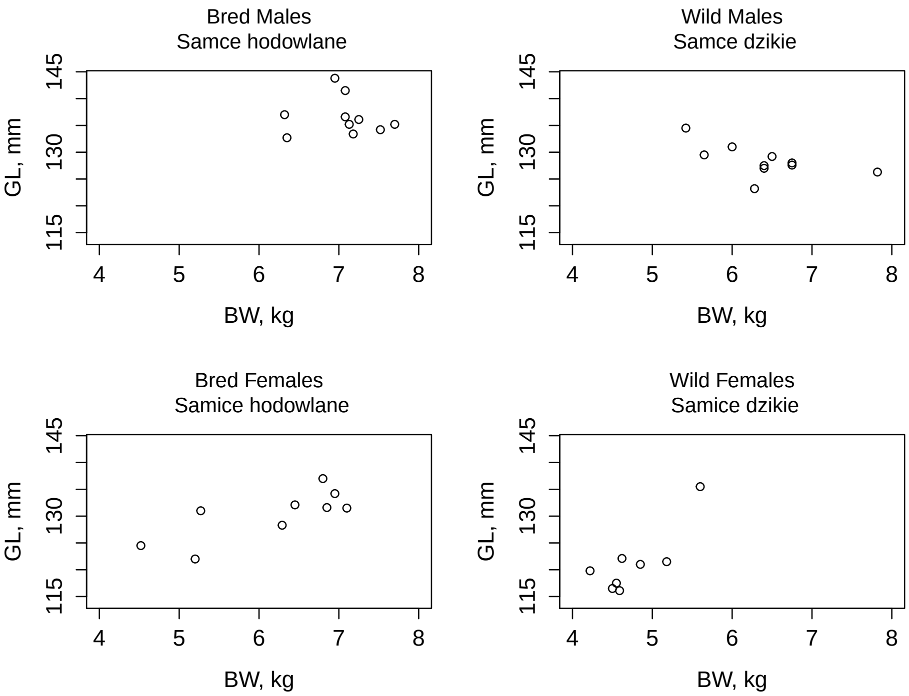

Fig. 2. Correlation between humeral greatest length and body weight in wild and bred foxes of either sex

Rys. 2. Korelacja pomiędzy największą długością kości ramiennej a masą ciała u dzikich i hodowlanych lisów obojga płci

The results indicate a significant increase in nearly all values of the studied traits, both in terms of conformation (body weight) and the size of the bones measured in captive foxes. It is worth noting that the measurements of body weight and length in wild foxes revealed their clear sexual dimorphism, which was not observed in captive animals. This is probably due to selection for larger body sizes and unimpeded supply of food [Lynch, Hayden 1995, O'Regan, Kitchener 2005]. Similar body sizes of wild red foxes were reported by Lefebvre et al. [1999], who found that the body length of free-living foxes was 61.8 cm. Selection and keeping the red fox in captivity for many generations resulted primarily in a change in the body proportions and in disappearance of sexual dimorphism within the morphological features expressed, among others, in an increased length of the examined bones. The calculated theoretical lengths of limbs of male and female captive foxes were higher than those in wild foxes of either sex.

This study has revealed that foxes of both groups show significant ($P \leq 0.01$, $P \leq 0.05$) sexual dimorphism within the length of the bones and the breadth of the epiphyses of the long bones. Our findings are consistent with those obtained by Monchot and Gendron [2010], who studied undomesticated red and arctic foxes. These Authors found that the length of the humerus (GL) was 118.9 mm in females and 126.6 mm in males, as in the presented study. Also, the breadth of humeral proximal (BP) and distal (BD) ends showed a clear sexual dimorphism, as found in this study.

Wild foxes were characterized by an often twice higher variability in the examined metric traits (coefficients of variation ranged from 2.70 to 12.11%) of long bones, as compared to the values of captive foxes (coefficients of variation between 1.46 and 9.01%). In farm breeding, a properly conducted selection seeks to ensure that the animals are phenotypically similar; hence, as a result, biological variability has been reduced. Extensive biological variability, which characterizes the animals living in the wild, is an element needed for survival.

The age of the studied foxes, ranging 11–12 months, may have resulted in a lack of apparent differences in long bone surface patterns. Due to low body weights, the static strain was not a significant factor that could result in patterns on the bone surface. Dynamic strain, on the other hand, leaves traces of muscle attachment in older individuals. Hoyte and Enlow [1966] found that a rich outside relief of the humerus is characteristic for large mammals, and its structural details, which usually result from the contact with strong muscles, are very clear and sharp in old individuals.

Interestingly, there is a highly significant correlation between the humeral length and the breadth of the epiphyses and diaphysis in male wild foxes (Table 4). This may be the result of more compact bone, particularly in the shaft, but its amount depends on the force and nature of strains [Pauwels 1963].

CONCLUSIONS

In conclusion, our studies confirm the changes in vulpine body proportions reported by other authors. Farm-bred individuals demonstrated greater body weight yet smaller body length, and disappearance of sexual dimorphism in these characters. The metric traits of the scapula and humerus increased. The greatest breadth of the trochlea (BT), smallest breadth of humeral diaphysis (SD), smallest length of the *collum scapulae* (SCL), and the greatest length of the scapular glenoid process (GLP) attained lower values in captive foxes compared to wild ones. The study revealed that wild red foxes demonstrated distinct sexual dimorphism (in all the studied characters), which was confirmed statistically, whereas in captive foxes this kind of dimorphism had disappeared.

ACKNOWLEDGEMENT

The study was financed by the National Center for Research and Development, Poland, within the development project no. 12-0140-10.

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DOMESTYKACJA LISA POSPOLITEGO (*VULPES VULPES*) ODZWIERCIEDLONA W CECHACH METRYCZNYCH NIEKTÓRYCH KOŚCI PASA BARKOWEGO

Streszczenie. Celem badań było porównanie wartości cech morfologicznych elementów obręczy barkowej lisa pospolitego dzikiego i hodowlanego. Badania przeprowadzono na kości ramiennej, promieniowej, łokciowej i łopatce 24 lisów pospolitych dzikich i 20 lisów hodowlanych. Po uboju określono masę ciała i długość naturalną każdego osobnika, a na pobranym odcinku obwodowym przednim wykonano pomiary wymienionych kości, wykonano fotografie rzutów poziomych kości ramiennych i nasad tych kości. Analiza statystyczna wybranych cech szkieletu obręczy barkowej wskazuje na zwiększenie wartości większości cech badanych kości. Osobniki pochodzące z hodowli charakteryzowały się większą masą, ale mniejszą długością ciała. Stwierdzono istotne ($P \leq 0.01$; $P \leq 0.05$) różnice dymorficzne dla cech długości i szerokości nasad kości ramiennej i promieniowej oraz istotny ($P \leq 0.01$; $P \leq 0.05$) wpływ pochodzenia lisów na cechy długości tych kości.

Słowa kluczowe: domestykacja, kość łokciowa, kość promieniowa, kość ramieniowa, lis pospolity, łopatka

Accepted for print – Zaakceptowano do druku: 14.06.2013