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Cranial morphometry of the Eurasian lynx (*Lynx lynx* L.) from Croatia

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ABSTRACT

The last specimens of the autochthonous Eurasian lynx (*Lynx lynx*) in Croatia were exterminated in Primorsko-Goranska County in around 1903. Lynx dispersed back to Croatia after six animals were reintroduced to Slovenia from Slovakia in 1973. Today, lynx are under legislative protection in Croatia and its population is defined as highly endangered. Cranial morphometry was used to analyse a sample of 58 skulls obtained from animals of the reintroduced population in order to identify geographical variation, sexual dimorphism and sex-linked cranial characters. Eighty-five cranial measurements were recorded from each skull. Males were significantly larger than the females in 39 of the 85 cranial measurements, whereas only one measurement, the postorbital constriction, was greater in females. Our research indicates that lynx in Croatia are more similar to lynx from Czech than from Norway. No evidence was found for differences in cranial measurements between the Croatian reintroduced and the Balkan autochthonous lynx population, so there is no reason to define the later population as a separate subspecies, *Lynx lynx martinoi* ssp.

Key words: Eurasian lynx, *Lynx lynx*, skull, cranial measurements

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Introduction

Once spread all over Europe, Eurasian lynx (*Lynx lynx* L.*)* disappeared from most of its habitat during the 18th and 19th centuries, with populations remaining only in remote areas of Finland, Scandinavia, Siberia, Poland, and the Carpathian and Balkan peninsula mountains (Kosovo, West Macedonia, Albania) (BIENIEK et al., 1998; SOLDO, 2001; HRISTOVSKI, 2001; PAUNOVIĆ et al., 2001; BEGO, 2001; ZLATANOVA et al., 2001; SPASSOV et al., 2001; PANAYOTOPOULOU, 2001; BREITENMOSER-WÜRSTEN and BREITENMOSER, 2001). Habitat loss, depletion of lynx prey and intensive hunting (BREITENMOSER et al., 1998) were also reasons why the indigenous Eurasian lynx population disappeared from the Dinaric Mountains. The last specimens of indigenous Eurasian lynx in Croatia were exterminated in the Primorsko-Goranska County in around 1903 (FRKOVIĆ, 2001). During the 20th century lynx were not present in Croatia for over 70 years. However, Eurasian lynx dispersed to Croatia after three females and three males were reintroduced to Slovenia from Slovakia in 1973 (ČOP, 1988). The size of the recent population in Croatia is estimated to be up to 60 animals (MAJIĆ-SKRBINŠEK, 2004) and lynx in Croatia have been a strictly protected species since 1995 (ANONYM., 1995).

Lynx cranial measurements, as one of the relevant ecological traits, have been studied by numerous authors (SAUNDERS, 1964; KVAM, 1983; ANDERSEN and WIIG, 1984; GARCIA-PEREA et al., 1985; WIIG and ANDERSEN, 1986; WIIG and ANDERSEN, 1988; MIRIĆ and PAUNOVIĆ, 1992; BELTRAN and DELIBES, 1993; ČERVENÝ and KOUBEK, 2000; PERTOLDI et al., 2006), but little quantitative data on the physical characteristics of the indigenous (extinct) (MIRIĆ, 1972; MIRIĆ, 1978) and reintroduced (present) (GOMERČIĆ et al., 2009) Eurasian lynx population from Croatia are published. On the contrary, there are many scientifically unproved theories that animals from the indigenous population were smaller than the animals from the reintroduced population (SOVILJ, 2008).

The goal of this paper was to study the morphometrical characteristics of skulls belonging to the Croatian reintroduced lynx population in order to identify geographical variations, sexual dimorphism and sex-linked cranial characters. Especial emphasis was placed on a comparison of the now present, reintroduced Croatian lynx population with cranial data of the autochthonous lynx population present in Croatia until the 1900´s.

Materials and methods

Skulls of 58 Eurasian lynx were examined morphometrically, 16 males, 35 females, and seven specimens of unknown sex. Fifty-four skulls were trophy skulls obtained for examination from private collections in the Primorsko-Goranska County, Croatia while four skulls were deposited at the Department of Biology, Faculty of Veterinary Medicine University of Zagreb, Croatia. The cause of death was known for 47 of the examined specimens: 43 skulls belonged to animals shot in a hunt, two were caught in traps, and two were killed in traffic accidents. The location and time of the origin was known for 46 skulls. They were collected in the period from 1980 to 2004 in the Primorsko-Goranska County, Croatia. Data on the body mass was known for 47 specimens.

Cranial measurements were taken using digital calipers and read to one tenth of a millimeter. Eighty-five cranial measurements were obtained from each skull (Fig. 1). Thirty-seven measurements were similar for the left and for the right side of the skull. In the later analyses the mean value of the summarized left and right side value was used. In total 43 measurements were related to the cranial bones and 42 to the teeth. The recorded cranial measurements comprised those used by VON DEN DRIESCH (1976), WERDELIN (1981), WIIG and ANDERSEN (1986), GARCÍA-PEREA et al. (1985). For comparison with other lynx species and populations 19 cranial measurements were appropriate.

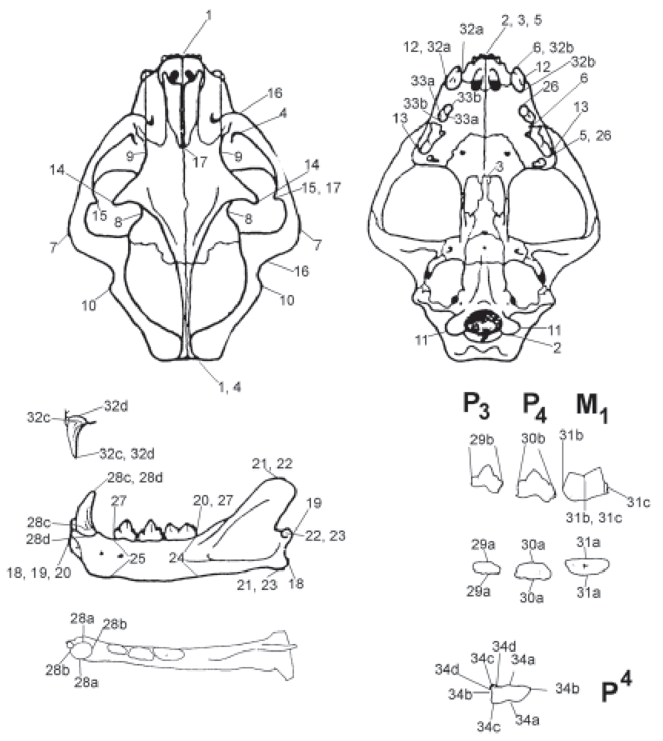

Fig. 1. Measurements of lynx skull, mandible, and teeth; the same ID number is used for the beginning and end point of the measurement

Fig. 1. Measurements of lynx skulls, mandibles, and teeth

1 - Profile length: from Prosthion (rostral end of the interincisive suture) to Akrokranion (the most caudal median point)
2 - (left and right) Condylobasal length: from Prosthion to the most caudal point of the occipital condyle
3 - Median palatal length: from Prosthion to Staphylion (tip of the caudal end of the median palatine suture)
4 - (left and right) Length from the most rostral point of the orbit to Akrokranion
5 - (left and right) Maxillar dental length: from Prosthion to the caudal margin of the fourth upper premolar (F^4) alveolus
6 - (left and right) Length from the rostral margin of the upper caninus (C^1) alveolus to the caudal margin of the upper third premolar (P^3) alveolus
7 - Zygomatic width: greatest width between the zygomatic arches
8 - Postorbital constriction: least width caudal to the zygomatic processes of the frontal bones
9 - Interorbital constriction: least supraorbital width
10 - Mastoid width: greatest width between the mastoid processes of the temporal bones
11 - Condylar width: width between the most lateral points of the occipital condyles
12 - Rostral width: between the lateral margins of the C^1 alveoli
13 - Maxillar dental width: between the lateral margins of F^4 alveoli
14 - Skull width between the tips of the zygomatic processes of the frontal bones
15 - Skull width between the tips of the frontal processes of the zygomatic bones
16 - (left and right) Length of the zygomatic arch: from the caudal margin of the infraorbital foramen to the most caudal point of the zygomatic process of the temporal bone
17 - (left and right) Length from Nasion (junction on the median plane of the right and left nasofrontal sutures) to the tip of the frontal process of the zygomatic bone
18 - (left and right) Mandibular length: form the most rostral point of the mandible to the caudal end of the angular process
19 - (left and right) Greatest mandibular length: from the most rostral point of the mandible to the most caudal point of the condyloid process
20 - (left and right) Mandibular dental length: from the rostral margin of the lower first incisor (I_1) alveolus to the caudal margin of the lower first molar (M_1) alveolus
21 - (left and right) Height of the ramus of the mandible: from the Coronion (dorsal border of the coronoid process) to the ventral border of the angular process
22 - (left and right) Height from the Coronion to the middle point of the condyloid process
23 - (left and right) Height from the middle point of the condyloid process to the ventral border of the angular process
24 - (left and right) Height of the body of the mandible at the caudal margin of the M_1 alveolus
25 - (left and right) Height of the body of the mandible at the rostral margin of the lower third premolar (P_3) alveolus
26 - (left and right) Length from the rostral margin of P^3 alveolus to caudal margin of the F^4 alveolus
27 - (left and right) Length from the rostral margin of P_3 alveolus to the caudal margin of M_1 alveolus
28a - (left and right) Lower caninus (C_1) width: between the lateral and medial surface of C_1 at the level of its insertion into the alveolus
28b - (left and right) C_1 length: between the rostral and caudal surface of C_1 at the level of its insertion into the alveolus
28c - (left and right) C_1 enamel height: from the tip of C_1 to the enamel margin
28d - (left and right) C_1 height: from the tip of C_1 to the margin of its alveolus
29a - (left and right) P_3 width: between the lateral and medial surface of P_3 at the level of its insertion into the alveolus

29b - (left and right) P_3 length: between the rostral and caudal surface of P_3 at the level of its insertion into the alveolus

30a - (left and right) Lower fourth premolar (P_4) width: between the lateral and medial surface of P_4 at the level of its insertion into the alveolus

30b - (left and right) P_4 length: between the rostral and caudal surface of P_4 at the level of its insertion into the alveolus

31a - (left and right) M_1 width: between the lateral and medial surface of M_1 at the level of its insertion into the alveolus

31b - (left and right) M_1 rostral length: from the rostral margin of M_1 to the middle notch at the level of its insertion into the alveolus

31c - (left and right) M_1 caudal length: from the middle notch to the caudal margin of M_1 at the level of its insertion into the alveolus

32a - (left and right) C^1 width: between the lateral and medial surface of C^1 at the level of its insertion into the alveolus

32b - (left and right) C^1 length: between the rostral and caudal surface of C^1 at the level of the insertion into the alveolus

32c - (left and right) C^1 enamel height: from the tip of C^1 to enamel margin

32d - (left and right) C^1 height: from the tip of C^1 to the border of its alveolus

33a - (left and right) P^3 width: between the lateral and medial surface of P^3 at the level of its insertion into the alveolus

33b - (left and right) P^3 length: between the rostral and caudal surface of P^3 at the level of its insertion into the alveolus

34a - (left and right) P^4 width without protoconus: between the lateral and medial surface of the P^4 at the level of its insertion into the alveolus

34b - (left and right) P^4 length: between the rostral and caudal surface of P^4 at the level of its insertion into the alveolus

34c - (left and right) P^4 width with protoconus: between the lateral and medial surface of P^4 at the level of its insertion into the alveolus

34d - (left and right) P^4 protoconus length: between the rostral and caudal margins of the protoconus

In order to include only adult skulls in the statistical analysis of the cranial measurements, the age of the examined specimens was determined. Age was determined by enumeration of root cementum annuli (KVAM, 1984). The third upper incisor (I3) was used for age determination. It was determined that a total of 11 skulls belonged to animals younger than 3 years, so further analyses included 47 adult specimens.

The cranial measurements were analyzed separately for females and males to detect sexual dimorphism and sex-linked cranial characters.

Results

The examined lynx skull sample included 16 males (31.4%), 35 females (68.6%), and seven specimens of unknown sex. The age was successfully determined in 55 animals (Fig. 2). Forty-four skulls belonged to animals aged three or more years. These skulls were defined as adult. Mean age for adults, animals older than three years, was 8.6 ± 3.4

years and 6.6 ± 2.8 years for males and females, respectively. The oldest female aged nine years. Six males were older than nine, with the oldest aged 15 years.

In three skulls the age could not be determined but they had hardly visible skull bone sutures and were defined as adult, too. Further analyses of body mass and cranial measurements (Table 1) included 47 adult specimens, 15 males, 25 females, and seven of unknown sex.

The body mass of the adult specimens ranged from 15 to 28 kg (mean: 21.9 kg), and from 12 to 25 kg (mean: 18.4 kg) in males and females, respectively. Adult male lynx had significantly greater body mass (P<0.01). Their body mass value was on average 16.2% higher than in females.

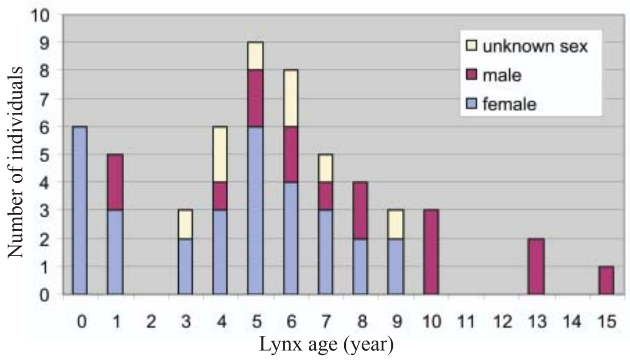

Fig. 2. Age distribution of Eurasian lynx (*Lynx lynx* L.) from Croatia

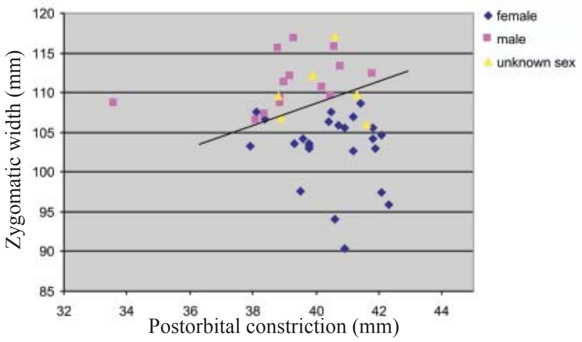

Fig. 3. Zygomatic width/postorbital constriction ratio indicates a sex-linked cranial feature in Eurasian lynx (*Lynx lynx* L.) from Croatia

Table 1. Age, body mass, and cranial measurements of adult Eurasian lynx (*Lynx lynx* L.) from Croatia (mean, standard deviation, range). Results of *t*-test for sexually dimorphic characters (p) and sexual difference (%).

	Male (n = 15)	Female (n = 25)	Male, female and unknown sex (n = 47)	p	Sexual difference (%)
Age (year)	8.6 ± 3.4 (4-15)	5.8 ± 1.7 (3-9)	6.6 ± 2.8 (3-15)	0.0025**	32.7
Body mass (kg)	21.9 ± 3.9 (15-28)	18.4 ± 3.2 (12-25)	19.8 ± 3.7 (12-28)	0.0043**	16.2
Measurement (mm) #					
1.	153.2 ± 7.4 (135.6-162.8)	145.5 ± 5.9 (133-154.5)	149.6 ± 7.8 (133-168.3)	0.0008**	5.0
2.	142.8 ± 3.7 (136.3-148.9)	133.5 ± 5.3 (121-141.5)	137.9 ± 6.7 (121-152.9)	0.0000**	6.5
3.	59.1 ± 1.5 (57-62.6)	55.8 ± 1.9 (52.5-58.9)	57.5 ± 2.5 (52.5-63.5)	0.0000**	5.6
4.	122.7 ± 2.9 (116.8-127.5)	115 ± 4.7 (103.4-121.7)	118.6 ± 5.6 (103.4-130)	0.0000**	6.3
5.	61.4 ± 1.5 (58.7-64)	58.3 ± 1.6 (54.8-60.9)	59.8 ± 2.2 (54.8-65)	0.0000**	4.9
6.	30.4 ± 1.1 (28.8-32.5)	28.4 ± 1.1 (25.8-30.4)	29.4 ± 1.5 (25.8-32.5)	0.0000**	6.6
7.	111.3 ± 3.2 (106.5-116.7)	103 ± 4.5 (90.3-108.6)	106.5 ± 5.7 (90.3-117.1)	0.0000**	7.5
8.	39.3 ± 2 (33.6-41.8)	40.5 ± 1.3 (37.9-42.3)	40.1 ± 1.6 (33.6-42.3)	0.0233*	-3.1
9.	33.2 ± 1.9 (30.2-36.6)	30.6 ± 2.1 (25.3-33.2)	31.9 ± 2.4 (25.3-36.9)	0.0003**	8.0
10.	67.7 ± 1.9 (65-70.7)	63.9 ± 2.3 (58.5-67.4)	65.6 ± 2.9 (58.5-71.7)	0.0000**	5.6
11.	32.2 ± 1 (30.2-33.6)	31.4 ± 1 (29.2-33)	31.8 ± 1.1 (29.2-33.6)	0.0227*	2.4
12.	40.6 ± 1.5 (37.8-43)	37.5 ± 1.5 (33.6-39.7)	38.8 ± 2.1 (33.6-43)	0.0000**	7.5
13.	62.8 ± 1.4 (60-64.8)	59.9 ± 1.3 (57.1-61.5)	61.2 ± 1.9 (57.1-64.8)	0.0000**	4.6
14.	74.3 ± 2.6 (69.2-77.2)	70 ± 4.2 (58.2-74.4)	71.7 ± 4.2 (58.2-79.1)	0.0039**	5.8
15.	87.1 ± 2.8 (83.2-92.1)	83 ± 3.2 (72.9-87.7)	85 ± 3.6 (72.9-92.1)	0.0003**	4.7
16.	77 ± 2.2 (72.6-79.5)	72.3 ± 3.4 (63-75.8)	74.6 ± 3.9 (63-83.3)	0.0000**	6.0
17.	52.9 ± 1.3 (51.4-55.5)	50.2 ± 2.2 (45.3-53.4)	51.5 ± 2.3 (45.3-55.8)	0.0001**	5.0
18.	106.8 ± 3.5 (101-114.5)	99 ± 4.7 (87.5-104.8)	102.5 ± 5.8 (87.5-114.6)	0.0000**	7.3
19.	106.7 ± 2.8 (102-110.5)	99.4 ± 4.4 (89-105.3)	102.6 ± 5.2 (89-113.1)	0.0000**	6.8
20.	61.6 ± 1.6 (59.3-64.4)	58.3 ± 1.6 (54.9-60.8)	59.7 ± 2.2 (54.9-64.4)	0.0000**	5.4
21.	46.6 ± 2 (43.6-49.6)	42 ± 2.2 (36.7-44.6)	44.1 ± 3.2 (36.7-51.7)	0.0000**	9.8

Table 1. (Continued)

22.	29.7 ± 1.5 (27.1-32)	27 ± 1.7 (22-29.1)	28.2 ± 2.1 (22-32.4)	0.0000**	8.9
23.	17.4 ± 1.1 (15.6-19.7)	15.4 ± 1 (13-17.1)	16.3 ± 1.4 (13-19.7)	0.0000**	11.2
24.	22.1 ± 1.1 (19.7-23.9)	20.3 ± 1.1 (18.1-22.3)	21.2 ± 1.4 (18.1-24.2)	0.0000**	8.2
25.	20.3 ± 0.8 (19-21.5)	19.2 ± 0.7 (17.8-20.2)	19.7 ± 1 (17.8-22.2)	0.0000**	5.7
26.	30.3 ± 1 (28.5-31.8)	29.3 ± 0.6 (28.3-30.5)	29.7 ± 0.9 (28.3-31.8)	0.0001**	3.5
27.	37.7 ± 1 (35.9-39.1)	36.6 ± 1 (34.7-38.8)	37.1 ± 1.1 (34.7-39.1)	0.0007**	3.0
28a.	6.9 ± 0.4 (6-7.6)	6.4 ± 0.2 (5.8-6.8)	6.7 ± 0.4 (5.8-7.6)	0.0000**	7.8
28b.	9 ± 0.5 (8-9.5)	8.4 ± 0.4 (7.6-9.4)	8.7 ± 0.5 (7.6-9.5)	0.0000**	7.5
28c.	17.5 ± 1 (15.4-19.3)	16.9 ± 0.8 (14.5-18.6)	17.1 ± 1.2 (11.9-19.3)	0.0004**	3.7
28d.	20.9 ± 2.7 (11.8-23.6)	19.9 ± 3.3 (5.6-25.9)	20.3 ± 3 (5.6-25.9)	0.3012	5.0
29a.	5.4 ± 0.3 (4.9-6)	5.3 ± 0.3 (4.8-6.1)	5.4 ± 0.3 (4.8-6.1)	0.7021	0.7
29b.	10.3 ± 0.4 (9.7-11)	9.9 ± 0.4 (8.7-10.5)	10.1 ± 0.5 (8.7-11.7)	0.0016**	4.0
30a.	5.9 ± 0.3 (5.5-6.4)	5.8 ± 0.4 (4.9-6.5)	5.9 ± 0.3 (4.9-6.5)	0.2608	2.0
30b.	12.4 ± 0.4 (11.8-13.4)	12.1 ± 0.4 (11.4-12.8)	12.2 ± 0.4 (11.4-13.4)	0.0083**	2.8
31a.	6.6 ± 0.2 (6.2-7)	6.5 ± 0.2 (5.9-6.9)	6.5 ± 0.2 (5.9-7)	0.1338	1.8
31b.	6.8 ± 0.4 (6-7.5)	6.5 ± 0.2 (6.1-7.1)	6.7 ± 0.3 (6-7.5)	0.0083**	4.0
31c.	10 ± 0.3 (9.3-10.3)	9.9 ± 0.3 (9.4-10.6)	9.9 ± 0.3 (9.3-10.6)	0.1156	1.6
32a.	7.8 ± 0.4 (7.2-8.6)	7.2 ± 0.3 (6.6-8)	7.5 ± 0.4 (6.6-8.6)	0.0000**	7.0
32b.	9.7 ± 0.5 (8.8-10.3)	9 ± 0.5 (8.5-10.7)	9.3 ± 0.6 (8.5-10.7)	0.0001**	7.0
32c.	18.4 ± 1.6 (14.5-20.2)	17.4 ± 2.8 (4.9-20.3)	18 ± 2.4 (4.9-20.9)	0.2481	5.2
32d.	23.5 ± 5.1 (6.5-27.7)	22.8 ± 2.9 (11.4-28.3)	23.3 ± 3.6 (6.5-28.3)	0.5399	3.3
33a.	6.4 ± 0.4 (5.6-6.9)	6.3 ± 0.3 (6.1-6.9)	6.4 ± 0.3 (5.6-7)	0.2868	1.6
33b.	11.9 ± 0.5 (10.9-13)	11.6 ± 0.3 (11-12.5)	11.7 ± 0.4 (10.9-13)	0.0085**	3.0
34a.	6.9 ± 0.2 (6.5-7.4)	6.7 ± 0.3 (6.3-7.5)	6.8 ± 0.3 (6.3-7.5)	0.0160*	3.0
34b.	18.4 ± 0.8 (16.6-19.3)	17.9 ± 0.4 (17.4-18.8)	18.1 ± 0.6 (16.6-19.5)	0.0000**	2.6
34c.	8.5 ± 0.4 (8-9.4)	8.2 ± 0.3 (7.7-8.7)	8.3 ± 0.4 (7.7-9.4)	0.0017**	4.2
34d.	3.2 ± 0.3 (2.8-3.9)	3.1 ± 0.2 (2.6-3.5)	3.1 ± 0.28 (2.6-3.9)	0.1306	4.3

*- P<0.05; **- P<0.01; [#]- the list and description of measurements are shown in Materials and methods

Table 2. Cranial measurements and body mass of the genus *Lynx*

		Lynx (*Lynx lynx*) from Croatia (this study)[a]	Lynx (*Lynx canadensis*) from Newfoundland (SAUNDERS. 1964)[b]	Iberian lynx (*Lynx pardinus*) (GARCÍA-PEREA et al., 1985)	Lynx (*Lynx lynx*) from Norway. (WIIG and ANDERSEN, 1986)[c]	Lynx (*Lynx lynx*) from Czech. (ČERVENÝ and KOUBEK, 2000)	Lynx (*Lynx lynx* from the Balkan (MIRIĆ, 1978, 1981)
Body mass (kg)	male	21.9 ± 3.9 n = 15 (15.0-28.0)	23.5 n = 94 (14.0-38.0)			21.8 ± 3.6 n = 25 (14.0-28.0)	
	female	18.4 ± 3.2 n = 25 (12.0-25.0)	18.9 n = 91 (11.0-26.0)			16.8 ± 2.7 n = 17 (13.0-22.0)	
Measurement (mm)[d]							
1.	male	153.2 ± 7.4 n = 15 (135.6-162.8)	129 ± 4.1 n = 23**	133.7 ± 2.5 n = 12 (128.7-137.8)**	153.1 ± 5.1 n = 75	153.3 ± 6.7 n = 43 (137.0-165.1)	151.8 n = 1
	female	145.5 ± 5.9 n = 25 (133.0-154.5)	122 ± 3.0 n = 13**	121.8 ± 4.2 n = 8 (113.6-126.2)**	143.0 ± 4.4 n = 56*	145.4 ± 6.3 n = 32 (130.2-157.1)	141.3 ± 1.2 n = 3 (140.0-142.3)
2.	male	142.8 ± 3.7 n = 15 136.3-148.9		121.7 ± 2.6 n = 10 (116.8-125.4)**	139.0 ± 4.4 n = 75**	139.3 ± 9.1 n = 43 (122.0-159.1)	136.5 n = 1
	female	133.5 ± 5.3 n = 25 (121.0-141.5)		110.0 ± 4.0 n = 7 (102.6-114.9)**	130.5 ± 3.8 n = 56**	131.4 ± 4.2 n = 32 (121.5-141.5)	127.8 ± 1.4 n = 3 (126.5-129.3)
3.	male	59.1 ± 1.5 n = 15 (57.0-62.6)		52.0 ± 1.6 n = 10 (49.9-55.4)**	58.9 ± 2.1 n = 75	57.1 ± 2.8 n = 43 (51.2-66.4)*	
	female	55.8 ± 1.9 n = 25 (52.5-58.9)		46.8 ± 2.1 n = 9 (43.8-49.7)**	55.3 ± 1.9 n = 56	54.8 ± 1.9 n = 32 (49.8-58.5)	
5.	male	61.4 ± 1.5 n = 15 (58.7-64.0)			60.8 ± 2.0 n = 75	54.7 ± 2.0 n = 43 (50.3-58.3)**	
	female	58.3 ± 1.6 n = 25 (54.8-60.9)			57.4 ± 1.7 n = 56*	52.9 ± 1.7 n = 32 (48.7-56.0)**	

Table 2. (Continued)

7.	male	111.3 ± 3.2 n = 15 (106.5-116.7)	94 ± 3.2 n = 24**	95.6 ± 2.3 n = 10 (92.9-100.8)**	101.3 ± 3.7 n = 75**	107.7 ± 5.6 n = 43 (97.0-118.2)*	106.1 n = 1
	female	103.0 ± 4.5 n = 25 (90.3-108.6)	89 ± 1.9 n = 13**	86.5 ± 4.3 n = 10 (80.9-93.5)**	95.4 ± 3.1 n = 56**	102.2 ± 3.4 n = 32 (92.3-108.6)	99.6 ± 2.5 n = 3 (97.8-102.5)
8.	male	39.3 ± 2.0 n = 15 (33.6-41.8)		39.8 ± 1.4 n = 12 (38.1-42.7)	37.8 ± 1.6 n = 75**	40.4 ± 2.7 n = 43 (32.8-46.8)	
	female	40.5 ± 1.3 n = 25 (37.9-42.3)		40.4 ± 1.1 n = 10 (39.2-42.6)	38.6 ± 1.9 n = 56**	39.2 ± 2.1 n = 32 (34.3-43.4)**	
9.	male	33.2 ± 1.9 n = 15 (30.2-36.6)			33.1 ± 1.6 n = 75	34.7 ± 3.3 n = 43 (28.4-44.0)	31.5 n = 1
	female	30.6 ± 2.1 n = 25 (25.3-33.2)			31.0 ± 1.4 n = 56**	33.1 ± 2.7 n = 32 (28.5-39.8)**	32.6 ± 1.4 n = 3 (31.2-34.0)
10.	male	67.7 ± 1.9 n = 15 (65.0-70.7)		58.2 ± 1.3 n = 11 (55.4-60.0)**	65.4 ± 2.0 n = 75**	65.9 ± 3.7 n = 43 (56.4-72.2)	
	female	63.9 ± 2.3 n = 25 (58.5-67.4)		53.5 ± 2.2 n = 8 (50.5-56.3)**	61.2 ± 1.7 n = 56**	62.4 ± 2.8 n = 32 (56.6-68.2)*	
11.	male	32.2 ± 1.0 n = 15 (30.2-33.6)			33.9 ± 1.0 n = 75**		
	female	31.4 ± 1.0 n = 25 (29.2-33.0)			32.7 ± 1.0 n = 56**		
12.	male	40.6 ± 1.5 n = 15 (37.8-43.0)		33.7 ± 0.9 n = 13 (32.0-35.1)**	39.2 ± 1.4 n = 75**		
	female	37.5 ± 1.5 n = 25 (33.6-39.7)		30.7 ± 1.6 n = 10 (28.1-32.4)**	36.7 ± 1.3 n = 56*		
13.	male	62.8 ± 1.4 n = 15 (60.0-64.8)			61.6 ± 1.8 n = 75*		
	female	59.9 ± 1.3 n = 25 (57.1-61.5)			58.9 ± 1.7 n = 56*		

Table 2. (Continued)

14.	male	74.3 ± 2.6 n = 15 (69.2-77.2)		63.8 ± 2.4 n = 8 (58.2-66.2)**		69.5 ± 4.4 n = 43 (57.9-78.2)**	
	female	70.0 ± 4.2 n = 25 (58.2-74.4)		57.7 ± 3.8 n = 7 (53.5-62.6)**		67.1 ± 2.7 n = 32 (61.6-73.4)**	
18.	male	106.8 ± 3.5 n = 15 (101.0-114.5)		89.0 ± 2.1 n = 12 (86.4-94.2)**	102.3 ± 3.5 n = 74**		106.9 n = 1
	female	99.0 ± 4.7 n = 25 (87.5-104.8)		79.7 ± 3.2 n = 11 (74.8-84.4)**	95.6 ± 3.0 n = 56**		99.9 ± 1.5 n = 3 (98.5-101.4)
19.	male	106.7 ± 2.8 n = 15 (102.0-110.5)		89.6 ± 1.9 n = 12 (87.5-94.5)**		103.1 ± 3.5 n = 43 (95.0-110.5)**	
	female	99.4 ± 4.4 n = 25 (89.0-105.3)		81.2 ± 3.1 n = 11 (76.2-85.3)**		99.5 ± 2.7 n = 32 (91.8-103.7)	
20.	male	61.6 ± 1.6 n = 15 (59.3-64.4)		48.9 ± 1.0 n = 12 (47.5-50.3)**	56.7 ± 1.7 n = 74**		
	female	58.3 ± 1.6 n = 25 (54.9-60.8)		44.3 ± 1.6 n = 10 (41.9-46.5)**	53.6 ± 1.6 n = 56**		
21.	male	46.6 ± 2.0 n = 15 (43.6-49.6)		37.1 ± 1.1 n = 12 (36.0-39.4)**	46.8 ± 2.2 n = 74	45.3 ± 2.7 n = 43 (39.0-51.2)	
	female	42.0 ± 2.2 n = 25 (36.7-44.6)		32.4 ± 2.1 n = 11 (29.5-35.0)**	42.4 ± 1.9 n = 56	42.0 ± 2.2 n = 32 (38.4-49.2)	
26.	male	30.3 ± 1.0 n = 15 (28.5-31.8)		24.6 ± 0.8 n = 14 (22.7-25.7)**			
	female	29.3 ± 0.6 n = 25 (28.3-30.5)		22.8 ± 1.0 n = 11 (20.6-23.7)**			
34b.	male	18.4 ± 0.8 n = 15 (16.6-19.3)		15.4 ± 0.5 n = 11 (14.4-16.2)**	18.6 ± 0.7 n = 74		18.1 n = 2 (17.5-18.7)
	female	17.9 ± 0.4 n = 25 (17.4-18.8)		14.3 ± 0.6 n = 11 (13.5-15.1)**	17.7 ± 0.8 n = 56		18.1 ± 1.3 n = 3 (17.2-19.5)

Table 2. (Continued)

34c.	male	8.5 ± 0.4 n = 15 (8.0-9.4)		7.2 ± 0.5 n = 11 (6.3-7.9)**			
	female	8.2 ± 0.3 n = 25 (7.7-8.7)		6.6 ± 0.4 n = 11 (5.9-7.3)**			

* - significantly differs from the Croatian population (P<0.05)

** - significantly differs from the Croatian population (P<0.01)

a - animals at age of 3 years and older

b - adults with fused epiphysis of the humerus

c - animals of age between 17 and 60 months, the measurements corrected to the value of 33.9 months old lynx

d- the list and description of measurements is in Materials and methods

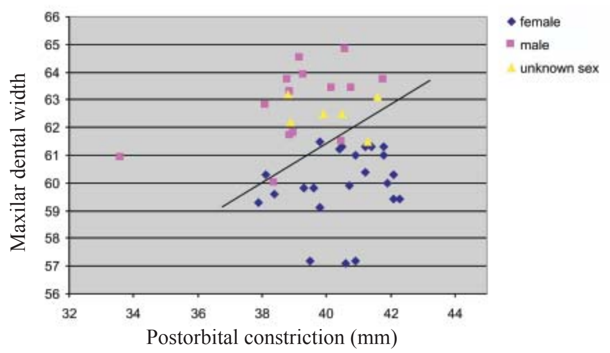

Fig. 4. Maxillar dental width/postorbital constriction ratio indicates another sex-linked cranial feature in Eurasian lynx (*Lynx lynx* L.) from Croatia

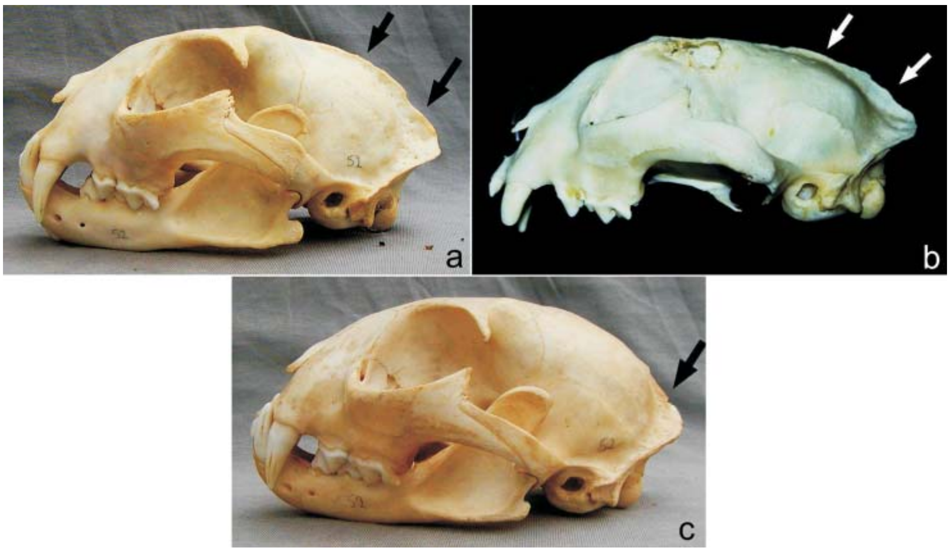

Fig. 5. Prominent external sagittal crest (crista sagittalis externa) in males (a: LS10, 8 years; b: LS52, 15 years) compared to a female (c: LS51, 8 years)

Males were significantly larger than the females in 39 (45.88%) of 85 cranial measurements. Only one cranial measurement, namely the postorbital constriction (8), was larger in females than in males. The value of the postorbital constriction was on average 3.1% higher in females than in males (Table 1). Values of male cranial measurements were on average 5% higher than in females, ranging from 0.7% to 11.2%. The main cranial characters such as the profile length (1) and the zygomatic width (7), were both significantly greater in males ($P<0.01$). Sex-linked cranial features are indicated in the zygomatic width/postorbital constriction ratio and maxillar dental width/postorbital constriction ratio. Both ratios are smaller in the males (Fig. 3 and Fig. 4). None of the nine teeth measurements (28d, 29a, 30a, 31a, 31c, 32c, 32d, 33a, 34d) showed any sexual dimorphism ($P>0.05$). The mid-dorsal external sagittal crest (crista sagittalis externa) was well developed in males, and in most male skulls it was very prominent, extending up to the caudal border of the frontal bones. The external sagittal crest was not prominent in any of the female skulls and did not extend as rostral as in males (Fig. 5).

Skull size showed a low correlation to the age and body mass. The profile length showed no correlation with the age ($R^2 = 0.0775$) and a very low correlation with the body mass (R^2 for both sexes = 0.1053, i.e. 0.148 and 0.116 for males and females, respectively).

Discussion

Our statistical analysis included 85 cranial measurements of 47 Eurasian lynx skulls from Croatia, belonging to animals older than 3 years. Namely, GARCIA-PEREA (1991) stated that lynx cranial measurements are age related and ANDERSEN and WIIG (1984) concluded that lynx skull growth stops at the age of three. The third upper incisor (I^3) has been used for age determination, which is different than the canine used in the work of CROWE (1972) and KVAM (1984). The I^3 has been used for age determination to avoid significant damage of the trophy skulls. Cranial morphometry was used to identify sexual dimorphism and sex-linked cranial characters, which have already been described in other lynx populations (GARCIA-PEREA et al., 1985; BELTRAN and DELIBES, 1993).

The Croatian population of Eurasian lynx expressed sexual dimorphism in skull size but also in body mass. Our results correspond with data of the Norwegian lynx (WIIG and ANDERSEN, 1986), where 15 cranial measurements were significantly larger in males than females, while only the postorbital constriction was significantly larger in females. Even though WERDELIN (1981) did not establish any statistically significant differences between male and female lynx skulls, because his study also included juvenile skulls, both WIIG and ANDERSEN (1986) and ČERVENÝ and KOUBEK (2000) confirmed sexual dimorphism in lynx skull size.

Skulls of male lynx from Croatian can be distinguished from the female skulls by the more prominent sagittal external crest and by two ratios: the zygomatic width/postorbital constriction ratio and the maxillar dental width/postorbital constriction ratio, which are both smaller in males.

Eurasian lynx from Croatia are significantly larger than the Iberian lynx (*Lynx pardina*) (GARCÍA-PEREA et al., 1985) in 14 out of 15 cranial measurements (Table 2). Cranial measurements of the Canadian lynx (SAUNDERS, 1964) are smaller than those of the Croatian Eurasian lynx (this study) but the body mass does not show a significant difference between these two lynx species (Table 2). Compared to other Eurasian lynx populations the Croatian population shows particular differences. The lynx from Croatia is more similar to lynx from the Czech Republic (ČERVENÝ and KOUBEK, 2000) than those from Norway (WIIG and ANDERSEN, 1986). The difference between Norwegian and Croatian lynx was established in 12 female and 9 male cranial measurements. Norwegian lynx have only two measurements greater in female skulls and one measurement greater in male skulls, while all other measurements were significantly smaller in skulls from Norwegian lynx. There are most similarities in the cranial measurements of the Croatian and Czech lynx populations. Out of 11 measurements compared only five are significantly different in males and females, respectively. Only one cranial measurement is larger in the Czech lynx (Table 2).

In his papers MIRIĆ (1978, 1981) defined a Eurasian lynx subspecies indigenous to the Balkan peninsula, *Lynx lynx martinoi* ssp. He based his statement on cranial measurements of three female and one male lynx from this region. The values of the female skulls measured by MIRIĆ (1974) did not show any statistically significant difference when compared with female skulls from our study. MIRIĆ (1978) measured six measurements in only one male skull and all of them were within the interval of two standard deviations of the reintroduced population, meaning that the dimensions of this skull are within the range of 95% of the dimensions of the skulls from the reintroduced lynx. Out of those six measurements in total four (1, 9, 18, 34b) are within the range of one standard deviation of the Croatian population of Eurasian lynx, meaning within 68% of the reintroduced population. MIRIĆ (1978) also stated that the body mass of the new subspecies is not larger than 25 kg. This value is not significantly different from the Croatian (21.9 ± 3.9 kg, range 15.0 - 28.0 kg) or Czech population (21.8 ± 3.6 kg, range 14.0 - 28.0 kg). Also when defining this new subspecies MIRIĆ (1978) stated that 30% of the animals from Balkan Peninsula have less visible or have no spots at all on their fur, compared to populations from Slovakia and the Caucasus mountains where only 10% of lynx have this kind of fur coloration. It is important to emphasize that only few years earlier the same author published an article saying that certain cranial measurements have proved to be a very reliable indicator for lynx taxonomy, while fur coloration and body dimensions are so variable they cannot be used to distinguish lynx species (MIRIĆ, 1974). In the same paper, based on cranial measurements of two male (one of them damaged and with a large number of measurements missing) and three female lynx skulls, MIRIĆ (1974) concluded that the Balkan lynx is completely the same as the European lynx, subspecies L. *l. lynx* L. MIRIĆ published the same idea in 1972: "Comparing the craniometrical characteristics of lynx from Yugoslavia we have seen that they do not differ from the craniometrical characteristics of the typical subspecies *L. lynx lynx.*". Even though the number of studied skulls has not increased, but only the number of studied furs for coloration and spots on pelts, MIRIĆ (1978) defined a new Eurasian lynx subspecies *Lynx lynx martinoi* ssp. Our research established that there is no significant difference between cranial measurements of the Balkan (MIRIĆ, 1978), Croatian (this research) and Czech lynx populations (ČERVENÝ and KOUBEK, 2000). Taking this into consideration and also the small number of skulls MIRIĆ (1978) studied, it is not justified to define the Balkan lynx population as a separate subspecies.

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SAŽETAK

Posljednji primjerci autohtonog euroazijskog risa (*Lynx lynx*) u Hrvatskoj istrijebljeni su oko 1903. godine na području Gorskog kotara. Ris se u Hrvatsku vratio nakon reintrodukcije šest životinja iz Slovačke u Sloveniju 1973. godine. Ris je danas u Hrvatskoj ugrožena, zakonom zaštićena vrsta. Kranijalna morfometrija rabljena je u analizi 58 lubanja risova iz reintroducirane populacije, s ciljem određivanja geografskih razlika, spolnog dimorfizma i spolno vezanih značajki lubanje. Ukupno je 85 mjera izmjereno na svakoj lubanji. Mužjaci su bili značajno veći u 39 od 85 mjera lubanje, dok je samo jedna mjera, najmanja širina lubanje aboralno od jagodičnih izdanaka čeonih kostiju, veća u ženki nego u mužjaka. Naše istraživanje pokazuje da je ris iz Hrvatske sličniji risu iz Češke nego onima iz Norveške. Nisu pronađeni dokazi o postojanju razlika u mjerama lubanje između reintroducirane populacije risa u Hrvatskoj i autohtone balkanske populacije, te stoga ne postoje temelji za definiranje balkanskog risa kao odvojene podvrste, *Lynx lynx martinoi* ssp.

Ključne riječi: kraniometrija, ris, *Lynx lynx*, Hrvatska
