Turkish Journal of Zoology
http://journals.tubitak.gov.tr/zoology/
Research Article

Turk J Zool
(2018) 42: 666-672
© TÜBİTAK
doi:10.3906/zoo-1802-39

Morphological variability of the baculum in *Martes foina* (Carnivora: Mustelidae) from Turkey

Ahmet Haris Selçuk ÖZEN*
Department of Biology, Faculty of Science and Literature, Dumlupınar University, Evliya Çelebi Campus, Kütahya, Turkey

Received: 25.02.2018 • **Accepted/Published Online:** 10.09.2018 • **Final Version:** 12.11.2018

Abstract: The present study was based on the bacula of 39 male (17 juvenile, 22 adult) stone marten (*Martes foina*) samples obtained from all geographical regions of Turkey between 1995 and 2016. Morphological variability in 11 characteristics of bacula was investigated. The purpose of this study was to measure numerical characters of the baculum, to identify relationships between measurements, and to evaluate variabilities in its morphology. Weight, total length, base length, base height, base width, apex height, apex width, median width, and median height were significantly greater in the bacula of adults compared to the bacula of juveniles. The most variable characteristic in adults was base width (18.96%). There was a significant relationship between some characteristics of the bacula measured. The strongest positive relationships were observed between median height and baculum weight (r = 0.771), weight and base length (r = 0.755), and median width and weight (r = 0.750) characteristics. Statistical analysis (PCA) also revealed a strong relationship between some characteristics. In particular, positive correlations between width and height sizes in the base (proximal), median, and distal of the baculum, as well as axis–apex height and apex width, suggest relationships that protect the urethra and baculum from fissures and fractures during copulation.

Key words: Stone marten, os penis, morphometry, variability, statistical analysis

1. Introduction

The baculum (os penis) is an extraskeletal bone located in the glans tissue at the distal end of the penis and is present in several mammalian species, including the order Carnivora (Patterson and Thaler, 1982; Abramov, 2002; Baryshnikov et al., 2003; Ferguson and Larivière, 2004; Ramm, 2007; Krawczyk and Malecha, 2009; Krawczyk et al., 2011; Vercillo and Ragni, 2011; Čanády and Onderková, 2016a, 2016b). The morphological structure of the baculum is specific to the species. Therefore, it is used as a distinctive characteristic to distinguish between species (Baryshnikov et al., 2003; Schulte-Hostedde et al., 2011; Sharir et al., 2011; Vercillo and Ragni, 2011). The baculum also varies between individuals of a species (Reinwaldt, 1961; Miller and Burton, 2001; Dyck et al., 2004; Malecha et al., 2009; Ramm et al., 2009). The functions of the baculum are to provide support during erection (Kelly, 2000), to protect the urethra (Baryshnikov et al., 2003), to stimulate the female reproductive tract during copulation (Krawczyk and Malecha, 2009), to ensure reproductive isolation between species, and to be an indicator of the male's condition (Čanády and Čomor, 2013).

Baculum variability of *Martes foina* has been researched in stone marten populations of the Czech Republic (Čanády and Onderková, 2016b) and Italy (Vercillo and Ragni, 2011). Stone marten is distributed in urban and rural residential areas of Turkey and uses barns, farms, wood storage, and attics of abandoned houses as its habitat (Özen and Gündüz, 2017). While hunting stone marten was previously permitted year-round, hunting is now only allowed in certain seasons. Stone marten has a wide distribution area in Turkey (Özen, 1999). However, there has been no study on morphological variability of the stone marten baculum in Turkey. The main goal of this study is to reveal numeric characteristics of baculum size in the *Martes foina* population of Turkey, analyze the relationships between the measured 11 characteristics of the bacula, and contribute to information about variability in morphology of the baculum of this species.

2. Materials and methods

Morphological analysis of the baculum was performed on 39 male (17 juvenile, 22 adult) samples of *Martes foina*. The samples were obtained as dead within the scope of two projects carried out between 1995 and 2016 in all geographical regions of Turkey (Figure 1).

The bacula were treated and cleaned according to standard procedures (Walton, 1968) and protected in

* Correspondence: aselcuk.ozen@dpu.edu.tr

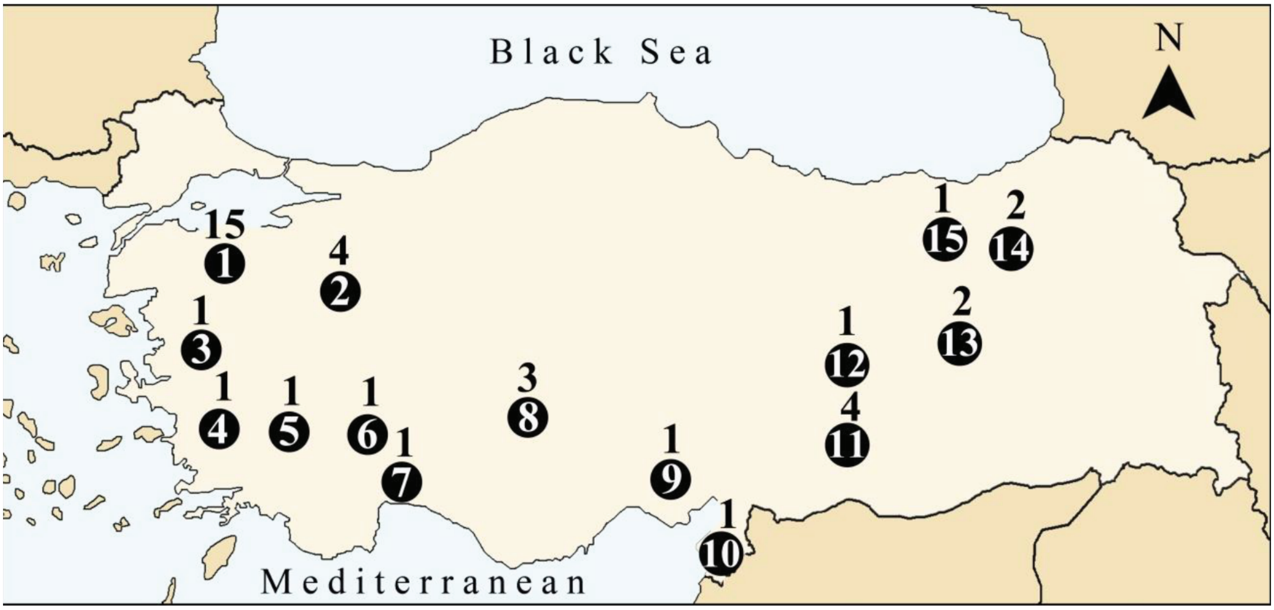

Figure 1. Localities where samples of *Martes foina* were obtained in Turkey (black numbers represent sample size, and white numbers show provinces: 1- Balıkesir, 2- Kütahya, 3- Manisa, 4- Aydın, 5- Denizli, 6- Burdur, 7- Antalya, 8- Konya, 9- Adana, 10- Hatay, 11- Adıyaman, 12- Malatya, 13- Bingöl, 14- Erzurum, 15- Bayburt).

museum boxes. Body weights (g) and the standard somatic measurements of head–body length, hind foot length, tail length, and ear height (all in mm) of all samples were recorded on labels. The bacula were treated according to Walton (1968), then washed with water and dehydrated in the air, and stored in museum boxes. While weights of the bacula were measured with a digital scale with 0.01 g precision, their lengths were measured with Vernier calipers with 0.02 mm precision.

The samples were defined as juvenile and adult based on the shape of the sagittal crest and clarity of the lambdoidal crest of the skull (Albayrak et al., 2008), differences in teeth erosion (Buchalczyk and Ruprecht, 1977), weight of the baculum (Van Soest and VanBree, 1970; Grue and King, 1984; Elsasser and Parker, 2008; Vercillo and Ragni, 2011), and length and shape of the baculum (Sumiński, 1968; Walton, 1968). Since morphological characters of a species were represented by adult members, juvenile samples needed to be distinguished from adults. In the present study, the data of the juvenile samples were used only to reveal differences between the juveniles and adults. Data from the adults were used in other analyses. Measurements of the baculum included 11 characteristics including the weight (Figure 2).

All samples were evaluated according to Čanády (2013), Čanády and Čomor (2013, 2015), and Čanády and Onderková (2016a, 2016b).

The obtained datasets were evaluated following statistical parameters: sample size (n), minimum and maximum (min–max), mean ($\bar{x}$), standard deviation (SD), and coefficient of variance (CV). All analyses were performed by using SPSS 24 (IBM Corp., Armonk, NY, USA). Normal distribution of the measurements was tested via Shapiro–Wilk W test (in all conditions, $P > 0.01$). The relationships between baculum measurements were analyzed using Pearson's coefficient of correlation (r). Morphometric variation of the bacula was examined with multivariate methods (principal component analysis [PCA]).

3. Results

Adult samples had greater significance of bacula differences than juveniles (Table 1).

The CV is an indicator of the characteristic of variability (homogeneity) and was identified only for adult samples. CV values were greater for some characteristics of the bacula. This situation was confirmed by PCA factors as well and indicated a greater variation. The results showed that the most variable characteristics of the baculum were base height, axis–apex height, weight, and width of base; the least variable characteristics were total length, median height, median width, apex height, and apex width (Table 2).

Analyses confirmed that there was a strong correlation between some variables of the baculum (Table 3).

The strongest correlations were between median height and baculum weight ($r = 0.771$, $P < 0.01$), weight and base length ($r = 0.755$, $P < 0.01$), median width and weight ($r = 0.750$, $P < 0.01$), weight and base width ($r = 0.645$, $P < 0.01$), and median width and base length (r

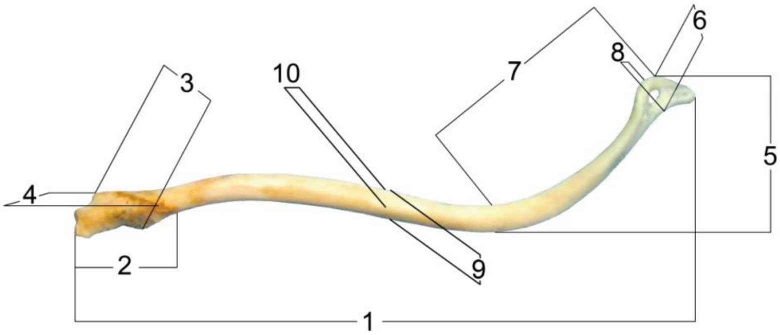

Figure 2. Measurements taken from the baculum of *Martes foina*: 1- total length (TL), 2- base length (BL), 3- base height (BH), 4- base width (BW), 5- axis–apex height (AAH), 6- apex height (AH), 7- slope length (SL), 8- apex width (AW), 9- median height (MH), 10- median width (MW) and weight (BP).

Table 1. A comparison of measured baculum traits between juvenile and adult individuals of *Martes foina*. Weight in grams, others in millimeters; n: number of sample, min–max: range margins, $\bar{x}$: mean, SD: standard deviation.

Measured traits	Juveniles			Adults			t-test	P
	n	Min–max	$\bar{x}$ ± SD	n	Min–max	$\bar{x}$ ± SD		
Weight (BP)	16	0.11–0.30	0.24 ± 0.05	22	0.38–0.67	0.53 ± 0.09	11.70	0.01
Total length (TL)	16	44.22–58.09	52.58 ± 3.54	22	56.98–66.06	60.87 ± 2.38	8.63	<0.01
Base length (BL)	16	2.45–5.27	4.18 ± 0.82	22	5.79–9.79	7.82 ± 0.97	12.16	<0.01
Base height (BH)	16	1.63–3.05	2.37 ± 0.40	22	2.48–5.50	4.26 ± 0.81	9.47	<0.01
Base width (BW)	16	1.72–3.89	2.60 ± 0.62	22	2.90–6.10	4.50 ± 0.74	8.36	<0.01
Axis–apex height (AAH)	17	6.50–14.07	11.06 ± 1.81	22	8.34–15.41	11.04 ± 1.87	–0.03	>0.01
Apex height (AH)	17	3.22–3.89	3.48 ± 0.20	22	3.28–4.65	3.84 ± 0.37	3.65	<0.01
Slope length (SL)	17	10.02–20.85	16.93 ± 2.55	22	12.87–20.31	16.76 ± 1.75	–0.24	>0.01
Apex width (AW)	17	0.86–1.30	1.06 ± 0.10	22	1.09–1.66	1.32 ± 0.13	6.34	<0.01
Median height (MW)	17	1.38–2.29	1.94 ± 0.21	22	2.16–2.95	2.59 ± 0.25	8.43	<0.01
Median width (MH)	17	1.59–2.62	2.16 ± 0.25	22	2.21–3.00	2.63 ± 0.21	6.26	<0.01

Table 2. Variation coefficient values (CVs) of measured baculum traits in adult individuals of *Martes foina*.

Measured trait	Adults
Weight (BP)	16.62
Total length (TL)	3.91
Base length (BL)	12.41
Base height (BH)	18.96
Base width (BW)	16.46
Axis–apex height (AAH)	16.91
Apex height (AH)	9.70
Slope length (SL)	10.45
Apex width (AW)	9.84
Median height (MW)	9.65
Median width (MH)	7.98

Table 3. Pearson's correlations between bacular traits of *Martes foina*. The upper number indicates the correlation coefficient values, the lower number represents the P-value. For abbreviations of baculum variables, see Figure 1 (NS: no significance).

	BH	BW	BL	AAH	AH	SL	TL	BP	AW	MW	MH
BH	1										
BW	0.463	1									
	0.05										
BL	0.353	0.543	1								
	NS	0.01									
AAH	−0.195	−0.158	0.005	1							
	NS	NS	NS								
AH	−0.030	−0.009	0.027	0.094	1						
	NS	NS	NS	NS							
SL	0.120	0.042	0.090	0.549	0.108	1					
	NS	NS	NS	0.01	NS						
TL	0.318	0.443	0.536	−0.337	0.148	0.084	1				
	NS	0.01	0.05	NS	NS	NS					
BP	0.367	0.645	0.755	0.095	0.133	0.256	0.521	1			
	NS	0.01	0.01	NS	NS	NS	0.05				
AW	−0.301	−0.175	−0.246	0.092	0.580	−0.204	−0.088	−0.186	1		
	NS	NS	NS	NS	0.01	NS	NS	NS			
MW	0.364	0.580	0.602	0.058	−0.031	0.187	0.300	0.750	−0.197	1	
	NS	0.01	0.01	NS	NS	NS	NS	0.01	NS		
MH	0.222	0.336	0.433	0.163	0.233	0.437	0.239	0.771	−0.063	0.536	1
	NS	NS	0.05	NS	NS	0.05	NS	0.01	NS	0.05	

= 0.602, $P < 0.01$). In addition, a strong correlation was also determined between apex width and apex height ($r = 0.580$, $P < 0.01$), median width and base width ($r = 0.580$, $P < 0.01$), slope length and axis–apex height ($r = 0.549$, $P < 0.01$), median height and median width ($r = 0.536$, $P < 0.05$), and base width and base height ($r = 0.463$, $P < 0.05$) (sample size was 22 for all).

According to PCA results, two principal components (PC1 and PC2) accounted for 54.67% of the variance (Table 4; Figure 3).

The first principal component (PC1) accounted for 37.45% of the total variance and showed a high correlation primarily with baculum weight (BP, $r = 0.903$, $R^2 = 0.815$), base length (BL, $r = 0.814$, $R^2 = 0.662$), base width (BW, $r = 0.784$, $R^2 = 0.614$), median width (MW, $r = 0.768$, $R^2 = 0.589$), and median height (MH, $r = 0.632$, $R^2 = 0.399$).

The second principal component (PC2) was responsible for 17.21% of the total variance and had a substantially good correlation with axis–apex height (AAH, $r = 0.859$, $R^2 = 0.737$), and slope length (SL, $r = 0.814$, $R^2 = 0.662$).

The third principal component (PC3) was responsible for 14.32% of the total variance and had a high correlation with apex height (AH, $r = 0.880$, $R^2 = 0.774$) and apex width (AW, $r = 0.867$, $R^2 = 0.751$).

There was a positive and relatively strong correlation between slope length and axis–apex height as well as base (proximal), median, and apex (distal) width and height of the baculum (Figure 4).

4. Discussion

The results show great variation in the measured characteristics of the stone marten's baculum. One of the factors causing these differences between bacula is the age of sampled individuals. Juveniles had smaller bacula than adults in terms of 9 of 11 characteristics analyzed. As in other mammal species (Reinwaldt, 1961; Sumiński, 1968; Walton, 1968; Buchalczyk and Ruprecht, 1977; Miller and Burton, 2001), this is characteristic for stone marten.

Descriptive statistics of baculum characteristics were compatible with the data of *Mustela putorius* (Malecha et al., 2009), *Procyon lotor* (Schwery et al., 2011), *Martes martes* and *M. foina* (Vercillo and Ragni, 2011), *Vulpes vulpes* (Čanády, 2013), *Canis lupus* (Čanády and Čomor, 2013, 2015), and *Martes foina* (Čanády and Onderková,

Table 4. Values of latent roots and loadings factors of the PCA for three main components (PC1–PC3): their eigenvalue, percentage (variability %), and cumulative percentage (cumulative %) expressions. For abbreviations of baculum variables, see Figure 1.

	PC1	PC2	PC3
BH	0.577	–0.114	–0.257
BW	0.784	–0.108	–0.084
BL	0.814	0.061	–0.059
AAH	–0.178	0.859	0.074
AH	–0.115	0.099	0.880
SL	0.152	0.814	–0.070
TL	0.691	–0.272	0.127
BP	0.903	0.279	0.058
AW	–0.270	–0.087	0.867
MW	0.768	0.228	–0.103
MH	0.632	0.502	0.180
Eigenvalue	4.120	1.894	1.576
Variance (%)	37.459	17.219	14.329
Cumulative (%)	37.459	54.677	69.006

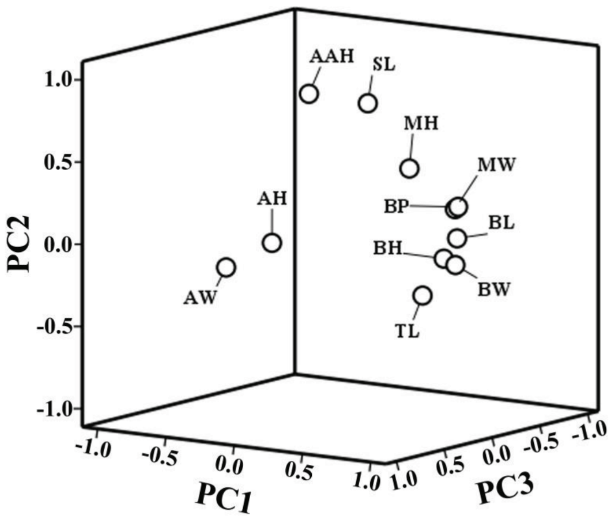

Figure 3. Results of the PCA for baculum variables in *Martes foina*. The ordination diagram shows the position of baculum variable scores on PC1, PC2, and PC3.

2016a, 2016b). However, mean values of baculum characteristics showed both similarities and differences with those found by Čanády and Onderková (2016b). Accordingly, weight and total length of the bacula in Turkey's population of stone marten are high, their base width and apex height are similar, and their apex width has low mean value. These differences were assumed to result from sample size, homogeneity, or geographical factors in both studies. In addition, the mean of total length data for bacula of *Martes foina* by Vercillo and Ragni (2011) ($\bar{x}$ = 58.83) was compatible with that of the Turkish population. Results reveal a high variability in thickness, weight, and axis–apex height of bacula represented by base height and base width, and low variability in total length. It has been stated that these high or low variabilities are likely to play an important role in increasing the strength of the baculum and to prevent possible fractures and fissures during copulation (Schwery et al., 2011; Čanády and Čomor, 2013). Moreover, positive correlations between width and height measurements in base (proximal), median, and end (distal) of the baculum also explained relationships for protecting the bone and urethra from fractures or fissures during copulation (Schwery et al., 2011; Baryshnikov et al., 2003; Čanády, 2013; Čanády and Čomor, 2013; Čanády and Onderková, 2016a, 2016b). Fractures of the baculum have been reported for the family Mustelidae (Long and Frank, 1968; Ewer, 1973; Dixon, 1995). According to Kierdorf (1996), fissures and fractures of the baculum can lead to death (Kierdorf, 1996). Ramm (2007) stated that the baculum is one of the competitive elements in the sperm race. The thickness and length of the baculum affect sperm transfer, ensuring ejaculation of semen and further stimulation of female reproductive system (Čanády, 2013). Females are sensitive to the thickness of the baculum depending on the length and care about this factor in choosing mates (Tasikas et al., 2009). In species from the family Mustelidae, the baculum is an indicator for genetic quality of males in carnivorous species that have copulation with multiple mates (Ferguson and Larivière, 2004).

Strong correlations of weight with variables of both length and width reveal the relationships that ensure interaction of the baculum with the female reproductive system and mechanical support during copulation (Baryshnikov et al., 2003; Krawczyk et al., 2011; Čanády and Čomor, 2013, 2015; Čanády and Onderková, 2016a, 2016b).

Tasikas et al. (2009) and Čanády and Onderková (2016b) expressed that thickness size, represented by width and height of the baculum, was quite variable compared to length. Schwery et al. (2011) confirmed that growth of weight and thickness (width and height) continued after growth of baculum length stopped. Baryshnikov et al. (2003) recorded that the urethral tract atrophied in the baculum of Mustelidae, ending with a sloping head with an asymmetrical distal end towards the apex; this head has an area with a hole in the genus *Martes*. All of these data are

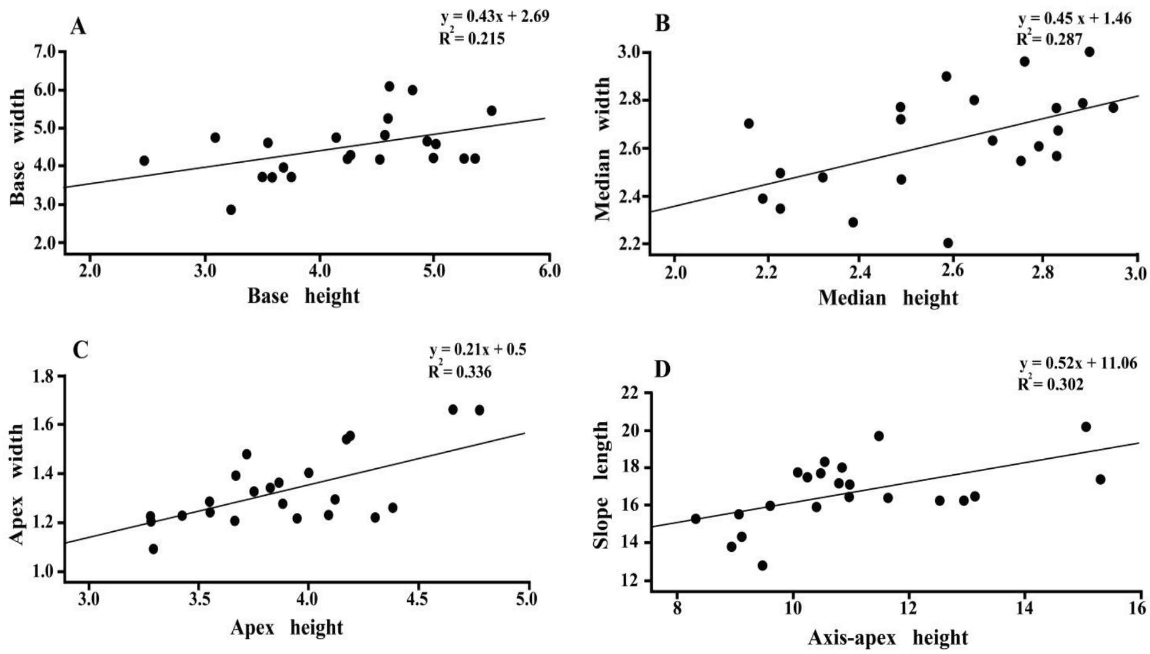

Figure 4. The relationships between measurements of the baculum: A) base width and base height, B) median width and median height, C) apex width and apex height, D) slope length and axis–apex height and slope length.

compatible with the data from bacula in the population of *Martes foina* in Turkey. Based on analysis and evaluation, it can be concluded that baculum structure and size of *Martes foina* in the Turkish population are variable. This variability is thought to be influenced by genetic, ecological, and zoogeographic factors. These results were also compatible with the data obtained from some carnivorous species by other researchers (Abramov, 2002; Baryshnikov et al., 2003; Malecha et al., 2009; Krawczyk et al., 2011; Čanády, 2013; Čanády and Čomor, 2013; Čanády and Onderková, 2016a, 2016b). Data and analysis of different populations are needed to exactly reveal the role and importance of the baculum of *Martes foina* during copulation.

References

Abramov AV (2002). Variation of the baculum structure of the Palearctic badger (Carnivora, Mustelidae, Meles). Russian J Ther 1: 57-60.

Albayrak İ, Özen AS, Kitchener AC (2008). A contribution to the age–class determination of Martes foina Erxleben, 1777 from Turkey (Mammalia: Carnivora). Turk J Zool 32: 147-153.

Baryshnikov GF, Bininda-Emonds ORP, Abramov AV (2003). Morphological variability and evolution of the baculum (os penis) in Mustelidae (Carnivora). J Mammal 84: 673-690.

Buchalczyk T, Ruprecht AL (1977). Skull variability of Mustela putorius L. 1758. Acta Theriol 82: 87-120.

Čanády A (2013). Variability of the baculum in the red fox (Vulpes vulpes) from Slovakia. Zool Ecol 23: 165-170.

Čanády A, Čomor Ľ (2013). Contribution to knowledge of the variability of the penis bone (baculum) in the Eurasian wolf (Canis lupus) from Slovakia. Lynx 44: 5-12.

Čanády A, Čomor Ľ (2015). Allometry of the baculum in the wolf (Canis lupus, Canidae) as an indicator viability and quality in males. Zool and Ecol 25:192-198.

Čanády A, Onderková A (2016a). Are size, variability and allometry of the baculum in relation to body length signals of a good condition in male weasels Mustela nivalis. Zool Anz 264: 29-33.

Čanády A, Onderková A (2016b). Notes on variation in the baculum of Martes foina from Czech Silesia, Czech Republic (Carnivora: Mustelidae). Lynx 47: 45-50.

Dixon AF (1995). Baculum length and copulatory behavior in carnivores and pinnipeds (Grand Order Ferae). J Zool Lond 235: 67-76.

Dyck MG, Bourgeois JM, Miller EH (2004). Growth and variation in the bacula of polar bears (Ursus maritimus) in the Canadian Arctic. J Zool Lond 264: 105-110.

Elsasser SC, Parker GH (2008). Morphometric criteria for distinguishing species and age-cohorts of ermine (Mustela erminea) and long-tailed weasel (M. frenata). Acta Zool 54: 75-88.

Ewer RF (1973). The Carnivores. London, UK: Cornell University Press.

Ferguson SH, Larivière S (2004). Are long penis bones an adaption to high latitude snowy environments? Oikos 105: 255-267.

Grue HE, King CM (1984). Evaluation of age criteria in New Zealand stoats (Mustela erminea) of known age. New Zealand J Zool 11: 437-443.

Kelly DA (2000). Anatomy of the baculum-corpus cavernosum interface in the Norway rat (Rattus norvegicus), and implications for force transfer during copulation. J Morphol 244: 69-77.

Kierdorf U (1996). Verheilte Baculum-Fraktur bei einem Iltis (Mustela putorius L). Z Jagdwiss 42: 308-310 (in German).

Krawczyk AJ, Malecha AW (2009). Variability of the mammalian os penis: phylogenesis and ecology. Kosmos 58: 179-185 (in Polish).

Krawczyk AJ, Malecha AW, Tryjanowski P (2011). Is baculum size dependent on the condition of males in the polecat Mustela putorius? Folia Zool 60: 247-252.

Long CA, Frank T (1968). Morphometric variation and function in the baculum, with comments on correlation of parts. J Mammal 49: 32-43.

Malecha AW, Krawczyk AJ, Hromada M (2009). Morphological variability of baculum (os penis) in the polecat Mustela putorius. Acta Zool Cracovi 52: 115-120.

Miller EH, Burton LE (2001). It's all relative: allometry and variation in the baculum (os penis) of the harp seal, Pagophilus groenlandicus (Carnivora: Phocidae). Biol J Linn Soc 72: 345-355.

Özen AS (1999). The status of tree marten (Martes martes) and stone marten (Martes foina) in Turkey (Carnivora: Martes). In: Tatlı A, editor. First International Symposium on Protection of the Natural Environment and Ehrami Karaçam (Pinus nigra Arnold. ssp. pallasiana (Lamb.) Holmboe var. pyramidata (Acat.) Yaltırık); Kütahya; 23–25 September 1999. Isparta, Turkey: Tuğra Press, pp. 577-584 (in Turkish).

Özen AS, Gündüz M (2017). The habitat diversity of the stone marten (Martes foina) in Balıkesir Province. Nature and Man 197: 24-29 (in Turkish).

Patterson BD, Thaler CS (1982). The mammalian baculum: hypotheses on the nature of bacular variability. J Mammal 63: 1-15.

Ramm SA (2007). Sexual selection and genital evolution in mammals: a phylogenetic analysis of baculum length. Am Nat 169: 360-369.

Ramm S, Khoo L, Stockley P (2009). Sexual selection and the rodent baculum: an intraspecific study in the house mouse (Mus musculus domesticus). Genetica 138: 129-137.

Reinwaldt E (1961). Über einen weiteren Fall von Fraktur des Baculums beim Fischotter (Lutra l. lutra L.) und die Art. Ihrer Entstehung. Arkiv Zool 13: 307-310 (in German).

Schulte-Hostedde A, Bowman J, Middel KR (2011). Allometry of the baculum and sexual size dimorphism in American martens and fishers (Mammalia: Mustelidae). Biol J Linn Soc 104: 955-963.

Sharir A, Israeli D, Milgram J, Currey JD, Monsonego-Ornan E, Shahar R (2011). The canine baculum: the structure and mechanical properties of an unusual bone. J Struc Biol 175: 451-456.

Sumiński P (1968). Der Penisknochen als Altersmerkmal des Raubwildes. Beitr Jagd und Wildforsch 6: 205-209 (in German).

Tasikas DE, Fairn ER, Laurence S, Schulte-Hostedde AI (2009). Baculum variation and allometry in the muskrat (Ondatra zibethicus): a case for sexual selection. Evol Ecol 23: 223-232.

Van Soest RWM, Van Bree PJH (1970). Sex and age composition of a stoat population (Mustela erminea Linnaeus, 1758) from a coastal dune region of the Netherlands. Beaufortia 17: 51-77.

Vercillo F, Ragni B (2011). Morphometric discrimination between Martes martes and Martes foina in Italy: the use of the baculum. Hystrix 22: 325-331.

Walton KC (1968). The baculum as an age indicator in the polecat Putorius putorius. J Zool 156: 533-536.