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Orlando Schwery, Zürich; Berit A. Köhnemann, Frank-Uwe Michler, Tharandt;
Winand Brinkmann, Zürich

Morphometrical characterisation of a raccoon (*Procyon lotor* L.) population from Müritz National Park (Germany) by means of the Os baculum

Schlagworte/key words: Waschbär, raccoon, *Procyon lotor*, Penisknochen, penis bone, Baculum, Os baculum, Altersschätzung, age estimation, Morphometrie, morphometrics, Müritz-Nationalpark

Introduction

One of the most important issues in wildlife biology is to find ways to assess a population's demographic composition (Sanderson 1950; Kramer et al. 1999). Only if age profile, sex ratio and numbers of sexually mature individuals can be estimated, it is possible to accurately predict the population's dynamics over time, including its responses to changes in its environment or influences due to human activities. Finally, these insights will be crucial in order to determine the most appropriate management strategy.

Concerning age determination in raccoons, commonly considered traits are tooth wear (Johnson 1969; Grau et al. 1970), number of growth annuli in cementum (Johnson 1969; Heddergott 2008), canine pulpa width (Johnson 1969; Lutz 1991), ossification of epiphyseal cartilages (Sanderson 1961a; Johnson 1969; Fiero et Verts 1986), dry weight (Sanderson 1961b; Johnson 1969) and nitrogen content (Grau et al. 1970) of the eye lens, closure of cranial sutures (Junge et Hoffmeister 1980; Fiero et Verts 1986) and also weight and length of the Os baculum (penis bone, baculum, Os penis or Os priapi). All those methods have different degrees of accuracy and cover different ranges and groups of ages that can be distinguished. A number of them have been compared for mammals in general by Morris (1972) and for raccoons by Fiero et Verts (1986) and by Grau et al. (1970).

Characteristics of the Os baculum have previously been under investigation for several species and in a diverse range of contexts, including development (Wright 1950 in the Long-tailed Weasel; Murakami et Mizuno 1986 in rats), hormonal influences (Bok et al. 1942; Murakami et al. 1995 in rats), taxonomy (Clark 1953 in deer mice; Tumlinson et McDaniel 1984 in the bobcat; Abramov 2002 in badgers), phylogeny (Mondolfi 1983 in ursids), morphology (Long et Frank 1968 in carnivores and rodents; Baryshnikov et al. 2003 in Mustelidae), sexual selection (Miller et al. 1999 and Miller et Burton 2001 in seals; Hosken et al. 2001 in bats; Ramm 2007 in mammals in general), copulatory behaviour (Dixson 1987 in primates, 1995 in carnivores and pinnipeds; Dixson et al. 2004 in mammals in general; Larivière et

Ferguson 2002 in carnivores) and even its absence in humans (Gilbert et Zevit 2001).
The Os baculum's relationship with age and use in age determination has been investigated for the badger (Graf et Wandeler 1982; Hancox 1987; Lüps et al. 1987; Whelton et Power 1993), the mink (Elder 1951), the river otter (Friley 1949a), the Michigan beaver (Friley 1949b), the polar bear (Dyck et al. 2004), the red fox (Harris 1978), the harp seal (Miller et Burton 2001), the hooded seal (Miller et al. 1999), the Mediterranean monk seal (van Bree 1994, 1999), the fur seal (Scheffer 1950) and the polecat (Walton 1968).
For raccoons, weight and length of the Os baculum are classically used traits for age estimation (Sanderson 1950; Johnson 1969; Lutz 1991; Kramer et al. 1999; Heddergott 2008). Although only assessable post-mortem (exception see Sanderson 1950), quantifying these characteristics provides a comparatively easy method for age estimation, especially to separate juvenile from adult individuals (Morris 1972).
The present study, a cooperation between the University of Zürich (Switzerland) and the "Projekt Waschbär" (Germany), aims primarily at confirming that the previously observed relationship between weight of Os baculum and age also holds for the raccoon population from Müritz National Park. Additionally, the analysis of allometric relationships between a number of bacular traits and correlations with age, hind foot length and testicle mass aims at revealing further aspects of the functionality and ontogeny of this bone. From a methodological side, photograph-based digital measurements are taken and their consistency compared to the classical measurements is assessed.

Material and Methods

During the years 2006 to 2010, 46 Os bacula have been collected from road-killed, hunted or otherwise perished male raccoons from Müritz National Park (Fig. 1). The bones have been extracted at the Leibniz Institute for Zoo and Wildlife Research (Berlin, Germany), where also hind foot length and testicular weight of the corresponding individuals have been measured. The mean of left and right hind foot length and testicular weight respectively was computed and used for further analysis. At the University of Zürich (Switzerland) the remaining tissue on the bones was removed after an hour in simmering water. Further, the bones were degreased in petroleum ether for a week, then boiled for a while and dried for at least an hour. Finally, they were bleached in 3% hydrogen peroxide for five hours and dried again over a couple of days.
The individuals' age was determined by the wearing of teeth (Grau et al. 1970) and overall appearance. For five individuals the age was determined by counting cementum lines of canines (Johnson 1969). In order to refine our age estimate, we assumed the 1st of April as the day of birth for all individuals and calculated the number of days until their (known) date of death. In the following we will refer to individuals with an age lower than one year as juveniles, individuals between one and two years as subadults and individuals older than two years as adults. If not distinguishable, adults and subadults are pooled and called adults (with an indication that adult means older than one year of age).
Dry mass of the bones was measured to the nearest 0.001 g using precision scales (Kern EW 220-3NM) and the linear measurements

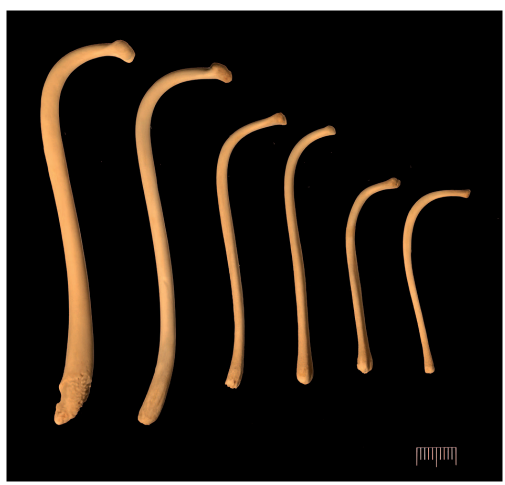

Fig. 1 Range of size and shape of the Os baculum in raccoons. Distal end pointing upwards, dorsal side pointing to the left. Estimated ages from left to right: 7 years, 2 ¼ years, 7 months, 5 ½ months, 4 ½ months, 4 months. Scale bar: 1 cm. Photograph: Rosi Roth

to the nearest 0.1 mm using a sliding calliper. Additionally, photos of the bones were taken (Nikon D2X, 4288x2848, 300dpi) and used to measure digital linear measurements to the nearest 0.01 mm using the program ImageJ (version 1.45a, source: http://imagej.nih.gov/ij). In order to evaluate the feasibility of these two measuring techniques, each individual was measured three times independently for each technique. The mean of these three measures per individual was calculated and the measures' deviation from the mean was used to estimate the accuracy. Further, the mean values of the classical measurements (except for A3) were used for further analyses of the data. To correct for general size increase, the ratio between each measured distance and A3 was computed. Both absolute and relative (size-corrected) values were subsequently used. The classical linear measurements are shown in Figure 2, the digital ones in Figure 3. For some individuals, data was missing on age (9 individuals plus one very old individual without age-replicate), linear measurements A1-3 and E (in case of healed or non-healed fractures, 5 individuals), linear measurement B2 (13 individuals; this measurement could not be taken for juveniles, as this part was still cartilaginous in these individuals and was removed during cleaning of the bone), hind foot length (5 individuals) and testicular weight (14 individuals). The respective specimens were excluded for every analysis which required one of the traits with missing information. All analysis and statistics tests were performed using IBM SPSS Statistics Version 19. Figures were done using R.

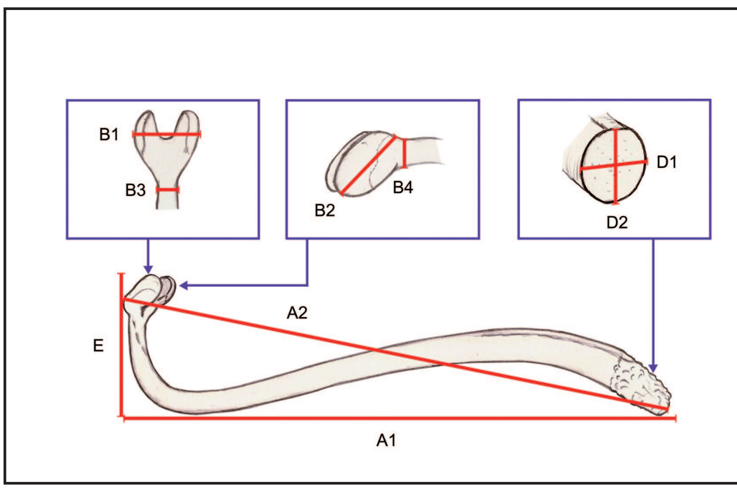

Fig. 2 Classical measurements performed on raccoon penis bones. Red bars: linear measurements. The measures represent two overall length estimates (A1, A2), the width and length of the distal cotyledons (B1, B2), the width and height of the thinnest point proximal of the cotyledons (B3, B4), the extremal width and height of the proximal end (D1, D2) and an estimate for the reach of distal curvature (E). Blue boxes: position of magnified parts

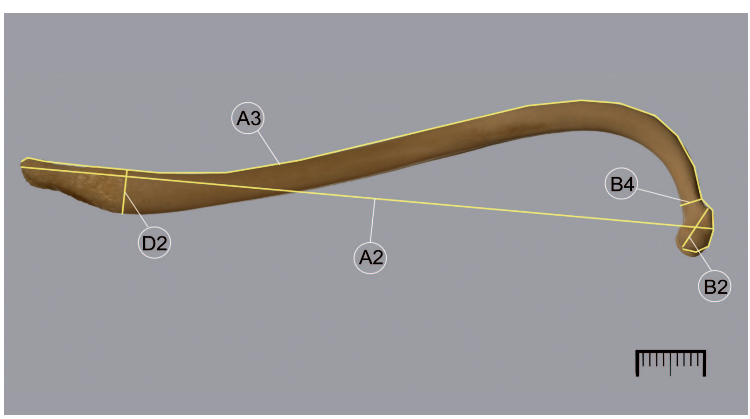

Fig. 3 Digital measurements performed on raccoon penis bones. Yellow lines: linear measurements. The measures represent two overall length estimates (A2, A3), the length of the distal cotyledons (B2), the height of the thinnest point proximal of the cotyledons (B4) and the extremal height of the proximal end (D2). Scale bar: 1 cm. Photograph: Rosi Roth

Results

Measuring methods

The means and ranges for all linear measures taken are shown in Table 1 for the whole sample and both juveniles and adults (older than one year) separately. A comparison of the four measurements that were covered by both methods (A2, B2, B4, D2) reveals a good overall concordance (data not shown). The means of the three measurements per individual only differ slightly between the two methods, with no difference exceeding 1.6 mm and an overall mean difference of 0.384 mm (A2: maximal difference 1.593 mm, mean difference 0.660 mm; B2: maximal difference 0.723 mm, mean difference 0.228 mm; B4: maximal difference 0.710 mm, mean difference 0.319 mm; D2: maximal difference 1.513 mm, mean difference 1.315 mm). The digital measurements consistently give higher results for B4 (all higher) and D2 (41 of 46 higher), indicating a slight methodological bias. The deviation of the three measurements from their mean does not exceed 1 mm with an overall mean of 0.115 mm. There were no apparent differences in deviation between the two measuring techniques. The expenditure of time was similar for both methods. The classical measurements take longer than the digital ones in performing them and in manually entering the data, but the digital ones in turn need additional time for taking the pictures of the bones.

The baculum as age estimate

The weights of the Os bacula range from 0.178 g to 3.827 g (mean: 1.883 g, n=46). When plotted against age (Fig. 4), a clear positive relationship becomes evident. Aside from that, the clustering into age cohorts is only evident between juveniles (range: 0.178 g to 0.734 g, mean: 0.391 g, n=12) and both subadults and adults together (range: 1.342 g to 3.827 g, mean: 2.480 g, n=25). A further separation of subadults and adults does not seem to be possible based on the present data. All juveniles showed a cartilaginous distal end, whereas the distal end of all subadults and adults was fully ossified.

If age is plotted against one of the length measures (Fig. 5) the age cohorts are apparent as well, though the transition between them seems more gradual. Again, it is possible to separate two clusters, one representing juveniles, the other subadults and adults together (ranges see Tab. 1) but not subadults from adults, due to the considerable overlap of these classes.

Allometric and ontogenetic relationships

All correlations between the measured distances on the bones are highly significant (Pearson, two-tailed, significance level 0.01; B2-A1, B2-A2, B2-A3, E-D1 and E-D2 with significance level 0.05), except for the correlations of B2 with B4, D1, D2 and E respectively. Further,

Table 1 Digital and classical linear measurements performed on raccoon penis bones. Means, extremal values and sample sizes are indicated for the whole sample and for both juveniles (age < 1 year) and adults (age > 1 year) separately

	Digital Measurements					Classical Measurements								
	A2 [mm]	A3 [mm]	B2 [mm]	B4 [mm]	D2 [mm]	A1 [mm]	A2 [mm]	B1 [mm]	B2 [mm]	B3 [mm]	B4 [mm]	D1 [mm]	D2 [mm]	E [mm]
All														
mean	84.661	98.826	5.780	2.567	5.426	83.240	84.854	5.978	5.988	2.918	2.248	5.814	5.128	20.732
min	45.093	52.890	3.950	1.777	2.437	43.967	45.667	2.867	3.900	1.500	1.500	3.467	2.433	14.167
max	103.573	120.030	7.073	3.240	8.337	101.867	103.200	8.267	7.400	3.800	2.900	8.733	7.767	26.700
n	41	41	33	46	46	41	41	46	33	46	46	46	46	41
Juveniles														
mean	59.433	70.709	-	2.111	3.920	57.378	59.250	3.987	-	2.292	1.756	4.418	3.497	18.325
min	45.093	52.890	-	1.777	2.437	43.967	45.667	2.867	-	1.500	1.500	3.500	2.433	14.167
max	71.867	84.550	-	2.357	4.917	69.500	71.233	6.300	-	2.933	2.167	6.400	4.667	24.333
n	12	12	-	13	13	12	12	13	-	13	13	13	13	12
Adults														
mean	95.100	110.460	5.780	2.747	6.020	93.941	95.449	6.762	5.988	3.165	2.441	6.364	5.771	21.728
min	75.823	88.063	3.950	2.257	2.703	73.733	75.533	5.067	3.900	2.267	1.933	3.467	2.600	17.167
max	103.573	120.030	7.073	3.240	8.337	101.867	103.200	8.267	7.400	3.800	2.900	8.733	7.767	26.700
n	29	29	33	33	33	29	29	33	33	33	33	33	33	29

all measures correlate significantly with age, bacular weight, hind foot length and testicular weight (Pearson, two-tailed, significance level 0.01; 0.05 for B2 correlated with age and bacular weight and E correlated with age and testicular weight), with exception of B2, which does not significantly correlate with hind foot length and testicular weight. Age, bacular weight, hind foot length and testicular weight also correlate significantly among each other (Pearson, two-tailed, significance level 0.01; 0.05 for bacular weight against testicular weight), except for hind foot length against testicular weight.

For the size-corrected measures, only a few correlations remain significant, that is to say correlations between A1-A2, B1-B2, B3-B4, D1-B3/B4/D2 and E-A1/A2/B4 (Pearson, two-tailed, significance level 0.01). Further, on a lower

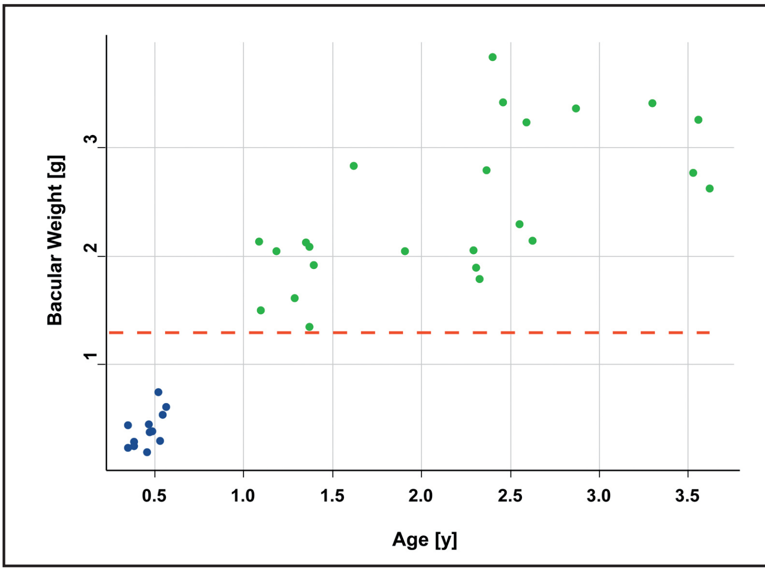

Fig. 4 Relationship of bacular weight and age in raccoons. Blue dots: cartilaginous distal end; green dots: ossified distal end; orange dashed line: assumed juvenile/adult separation value at 1.3 g; n= 36.

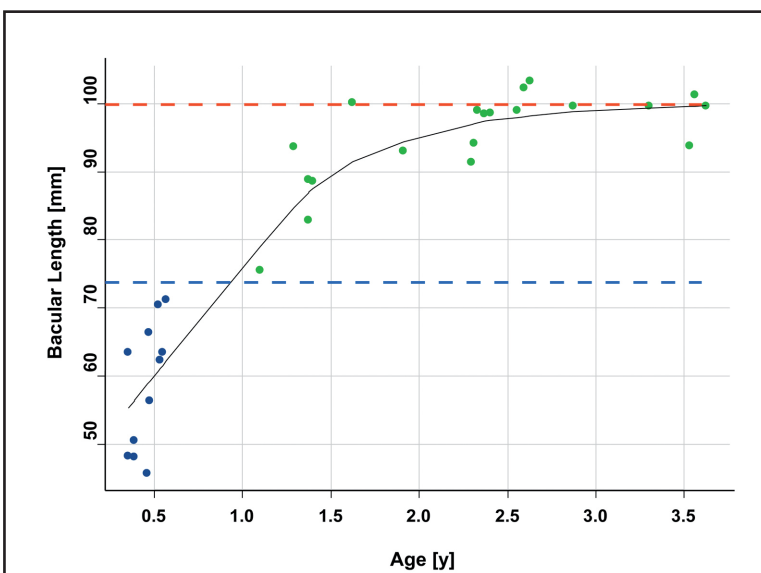

Fig. 5 Relationship of bacular length (A2) and age in raccoons. Blue dots: cartilaginous distal end; green dots: ossified distal end; black line: smoothing line (span: 0.65); blue dashed line: assumed juvenile/adult separation value between 72–75 mm; orange dashed line: assumed maximal length around 100 mm; n=31.

level (Pearson, two-tailed, significance level 0.05), E correlates with B3 and B2 correlates with B3. All measures correlate significantly with age (Pearson, two-tailed, significance level 0.01; 0.05 for B1) and bacular weight (Pearson, two-tailed, significance level 0.01; 0.05 for B1, B3 and B4), except for B2, D1 and D2 plus B3 in case of age. B1, B4 and E correlate significantly with hind foot length (Pearson, two-tailed, significance level 0.05) whilst A1, B3, B4 and E correlate significantly with testicular mass (Pearson, two-tailed, significance level 0.05, 0.01 for E).

Discussion

Measuring methods

The classical measuring using a calliper is comparatively easy to perform and most measured distances can be assessed with a reasonable precision and accuracy. However, one could imagine distances which could not be measured easily with a calliper and at some scale distances are too small to be measured.

The digital method has the advantage of potentially higher precision. Together with the possibility of performing the measurements on magnified pictures, it makes this method especially useful for measuring very short distances and distances that cannot be measured with a calliper, like A3. However, if the end points of the distances are not well defined enough, this will reduce the accuracy of the method because it then relies on the visual judgement of the investigator. Furthermore, it is not always possible to capture all sections to be measured on one picture (like B1, B3 and D1) which would make it necessary to take several pictures per specimen. Also, some measures would require auxiliary lines (like A1 and E). Both cases would greatly increase time and effort necessary to perform digital measures compared to performing classical ones. Also, other three dimensional objects can have conformations that make it impossible to capture the sections to be measured in the required way on a photograph.

The bias for consistently higher values measured with the digital method in case of B4 and D2 might reflect the fact that extremal points (a minimum in case of B4, a maximum in case of D2) can be "felt" in case of measuring with a calliper, whereas it is a matter of visual judgement for digital measures. Hence, the classical measurements would be more accurate, whereas the digital ones would systematically overestimate these values.

In conclusion, it seems that both measuring techniques are feasible for the purpose under discussion. The amount of time to perform measurements is more or less equal for both techniques. However, both have their advantages and limitations which might become important under certain circumstances and would require adjusting the method to the respective needs.

The baculum as age estimate

The present data confirms for the raccoon population in Müritz National Park that weight, length and distal ossification of the Os baculum are reliable traits to differentiate juveniles from adults (older than one year). This result is in accordance with previous studies on that issue (for weight: Fiero et Verts 1986; Heddergott 2008; Lutz 1991; Kramer et al. 1999; Johnson 1969; Sanderson 1950; for length: Sanderson 1950; Kramer et al. 1999; for ossification of distal end: Sanderson 1950; but see Heddergott 2008). However, unlike the studies of Heddergott (2008), Lutz (1991) and Johnson (1969) a similar separation of subadults and adults based on bacular weight or length does not seem apparent, as reported by Fiero et Verts (1986), Kramer et al. (1999) and Sanderson (1950, though he assumed it to be possible). One reason for this might lie in our age estimations based on tooth wear, as the accuracy of other methods would be higher (Grau et al. 1970; Fiero et Verts 1986).

A comparison of our bacular weight-data with other studies (Tab. 2) shows a general accordance for the ranges of both the whole data set and the age cohorts. The differences in the extremal values of the whole data set are very likely an effect of sample size. The separation value of 1.3 g (Fig. 4) for juveniles and adults (subadults and adults together), as proposed by Fiero et Verts (1986), is consistent for all studies except for Sanderson (1950). Johnson (1969) stated that juveniles would have a bacular weight below 1.2 g, but his data would be consistent with a boundary of 1.3 g. Kramer et al. (1999) used 2.5 g as cutoff value to separate immature from mature individuals which represents the boundary between subadult and adult animals since raccoons become reproductively active with an age of two years (Gehrt 2003). In the studies discriminating subadults and adults (Heddergott 2008; Lutz 1991; Johnson 1969) a bacular weight of 2.5 g would well fit the measured lowest weights for adults (2.546 g; 2.523 g; and 2.5 g respectively).

The only major discrepancy concerning the weight of the Os baculum arises from Sanderson (1950), who claims the cutoff value separating juveniles from adults to be 2 g, though his data also shows a considerable overlap between the two age groups (Tab. 2). This might be explained by his sample size (n=545), which is by far higher than in any other study considered here. Another possible explanation could lie in the use of distal ossification as age criterion. Since the process of ossification is fundamentally a gradual one, there might be different practices in scoring the ossification of the distal end into mainly cartilaginous and mainly ossified. Sanderson (1950) states that "all males become sexually mature and lose the cartilage from their penis bones before their second fall", probably indicating that after this there is no cartilaginous material detectable at all. Nevertheless, he classifies animals with cartilaginous distal ends as younger than one year and animals with an ossified distal end as older than one year. This and the assumption that after the first year the biggest part of the distal cotyledons is already ossified indicate that differential scoring of the distal end leads to different estimates of age.

Sanderson (1950) and Kramer et al. (1999) also used bacular length to separate juvenile raccoons from adult ones (or mature from immature in case of Kramer et al. 1999) and they claimed the boundary to be at 90 mm. Again, considering length-data from the study at hand, this value may be suitable for distinguishing immature from mature individuals (what more or less would correspond to subadults and adults). The length ranges of the raccoons from Müritz National Park (Tab. 1) in contrast indicate the separation value to be between 72–75 mm (Fig. 5). Just as in the case of weight, different ways of scoring the state of ossification on the distal end might have lead to diverging age-group estimations and thus different cutoff values. However, in case of length one must be cautious when comparing different studies, since there are different ways of measuring it (as reflected by the three different length estimates used in this study) and it is not always made clear which way is applied.

Allometric and ontogenetic relationships

The correlations of all unstandardised measures are likely to reflect general increase in size. All bacular traits under investigation grew larger with increasing age and therefore also with increasing bacular weight, length (A1, A2, A3) and testicular weight. Correlations of size-

Table 2 Comparison of bacular weight ranges in different studies on raccoon penis bones. Extremal values are indicated for the whole sample and for both juveniles (age < 1 year) and adults (age > 1 year) respectively. To ensure comparability, subadults and adults have been grouped together in this table, if they were distinguished in the respective study.

Study	Total Range min. [g]	Total Range max. [g]	Range Juveniles min. [g]	Range Juveniles max. [g]	Range Adults min. [g]	Range Adults max. [g]
present study	0.178	3.827	0.178	0.734	1.342	3.827
Fiero et Verts 1986	0.300	5.670	0.300	1.220	2.030	5.670
Heddergott 2008	0.102	4.603	0.102	1.261	1.319	4.603
Lutz 1991	0.104	4.518	0.104	1.277	1.324	4.518
Johnson 1969	-	5.400	-	1.200	1.500	5.400
Sanderson 1950	0.400	7.200	0.400	2.200	1.600	7.200

corrected measures on the other hand are more likely to reflect allometric relationships.
As previously observed by SANDERSON (1950), it seems that at the age between 1.5 and 2.5 years, the length of the penis bone meets a maximum around 100 mm (Fig. 5), despite further increase in weight (Fig. 6). Such a development of length and weight has often been reported for penis bones (e.g. VAN BREE 1999). It might suggest that higher length would not increase the animal's fitness, most likely for reasons linked to the anatomy of the female reproductive tract. It would also be possible that this maximal length represents an optimum, though this question cannot be addressed appropriately with the current data.
A similar maximum appears to exist for B1 around 7.25 mm (Fig. 7), corresponding to the

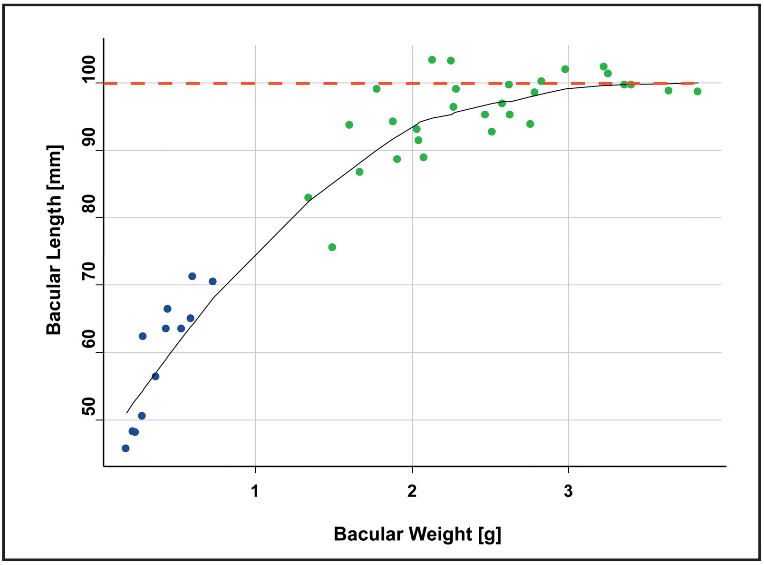

Fig. 6 Relationship of bacular weight and bacular length (A2) in raccoons. Blue dots: cartilaginous distal end; green dots: ossified distal end; black line: smoothing line (span: 0.45); orange dashed line: assumed maximal length around 100 mm; n= 41.

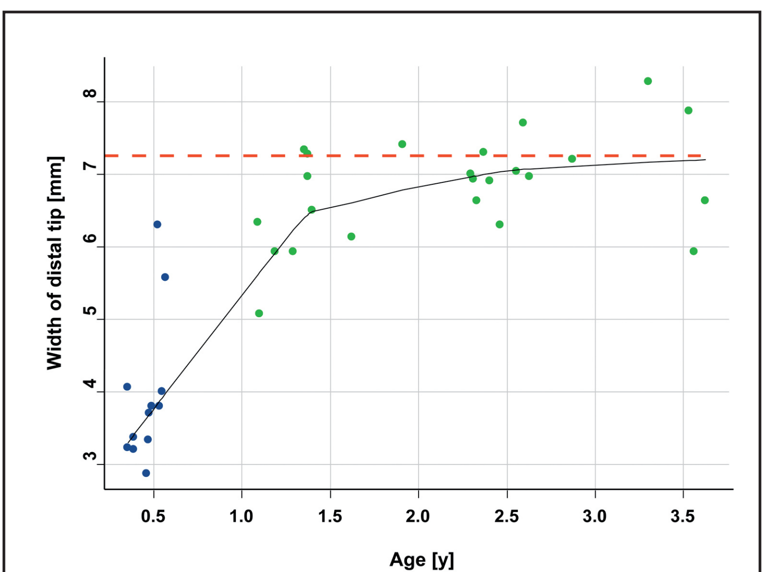

Fig. 7 Relationship of the distal tip-width (B1) of the Os baculum and age in raccoons. Blue dots: cartilaginous distal end; green dots: ossified distal end; black line: smoothing line (span: 0.65); orange dashed line: assumed maximal width around 7.25 mm; n= 36.

width of the tip. Again, it may relate to an interaction with female genital anatomy.
As the animal grows older, the reach of the bone's distal curve (E) grows larger, but relative to the length of the bone, it seems to get smaller (Fig. 8). This of course also holds in relation to bacular length and weight, as both increase with age, too (not shown). It reflects the development of the bone's curvature, but considering the progression of length growth (Fig. 5) it becomes clear that the reach of the curve rather stays more or less constant while the length increases. This constancy might have implications on the function and relating to that also the mechanical properties of the bone. What exactly it implies though, cannot be deduced from the present data. All three length estimates not only correlate among each other but also show

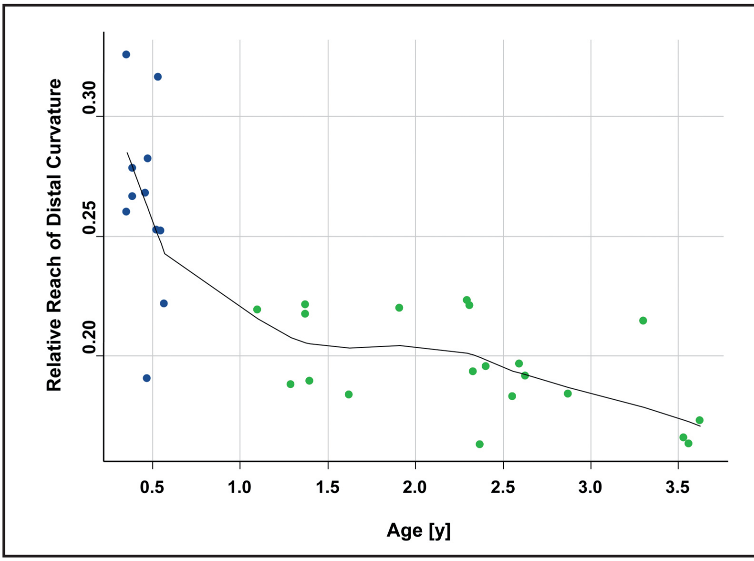

Fig. 8 Relationship of the relative (length-corrected) reach of distal curvature (E) of the Os baculum and age in raccoons. Blue dots: cartilaginous distal end; green dots: ossified distal end; black line: smoothing line (span: 0.40); n= 31.

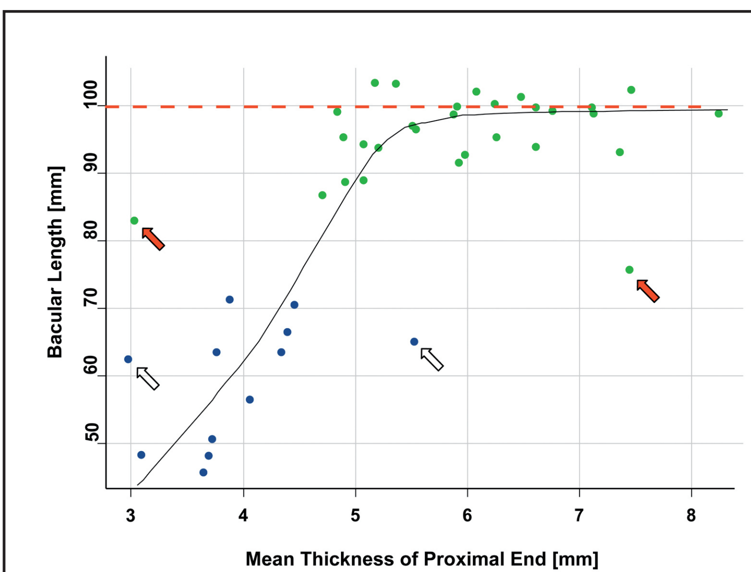

Fig. 9 Relationship of length and the thickness of the proximal end (mean of D1 and D2) of the Os baculum in raccoons. Blue dots: cartilaginous distal end; green dots: ossified distal end; red arrows: possibly pathological outliers; white arrows: unexplained outliers; black line: smoothing line (span: 0.60); n= 41.

very similar progressions in relation to other traits. The correlations of the length corrected values of B1 and B2, B3 and B4 and of D1 and D2 proceed more or less linearly, indicating that all these trait-pairs increase similarly with increasing bone length.

The progression of the bone's proximal thickening (D1, D2) in relation to length (Fig. 9; for the plot, the mean of D1 and D2 was taken because neither of the two measures was consistently the bigger one) reveals that the proximal end continues its growth after the length has reached its maximum. The same also holds for the thinnest point proximal to the cotyledons (B3, B4; not shown) and so assumedly for the whole shaft of the Os baculum. The increasing thickening, especially of the proximal end is generally observed in the development of penis bones (Morris 1972) and might at least partially explain the continued increase in bacular weight after growth in length stagnates. The proximal end of the bone is the part where musculature is attached (most likely used to eject the penis from its sheath) and also, this area is often rugose in older individuals (Fig. 1, leftmost specimen). Given that rugosity of muscle attachment sites is thought to be a reaction to mechanical stress (Robb 1998; Niinimäki 2009) this hints at the possibility, that cumulative mechanical stress and micro-traumata arising from copulation could trigger the bone's reaction to grow its proximal end more massive. Together with the generally increasing thickness (maybe a reaction of the bone to mechanical stress as well), this would cause the bone to become heavier even after its maximal length is reached (around the onset of sexual maturity). The fact that healed fractures are regularly encountered (Sanderson 1950; Lutz 1991; three individuals in present data set) supports the thought that considerable mechanical forces are acting on the bone.

The two adults of the highlighted outliers in Figure 9 (red arrows) might be of pathological nature, as the surface of the bone showed similar structure as in case of healed fractures. The two juvenile outliers (white arrows) could not be explained.

The general tendency for B2 not to correlate significantly with the other measures is probably due to the fact that this character could only be measured in adults, but not in juveniles, since their cotyledons were not ossified and got removed during preparation.

Despite the correlations, hind foot length showed only very unclear relationships with other traits (see also Lutz 1991 and Heddergott 2008 for bacular weight). It increases with age but still remains highly variable, therefore it is probably also not very useful for estimating age or might indicate that the traits under consideration are to some extent independent of body size.

Testicular weight also increases with age, with increasing variability towards the older ages (not shown), similar to bacular weight. Hence, all correlations of testicles mass with other traits most probably reflect age-dependent relationships.

In conclusion, the Os baculum of raccoons appears to be rather conserved in shape and size, suggesting it to be under selective pressure imposed by a series of forces. The overwhelming diversity in shapes (e.g. Burt 1960) and sizes of mammalian bacula and especially their species-specificity hints to the same conclusion. The nature of these forces however, remains elusive. It has previously been hypothesised that either increased rigidity of the penis (vaginal friction hypothesis, Long et Frank 1968), assistance in sperm transport (prolonged intromission hypothesis, Dixson 1987) or stimulation of the female reproductive tract (induced ovulation hypothesis, Greenwald 1956) might be the key to the bacular puzzle. These hypotheses have all gained some support by now and different studies also provided other hints concerning the function of the baculum. Scheffer et Kenyon (1963) found for pinnipeds that baculum length is related to whether mating takes place on land or in water. Dixson (1987, 1995; Dixson et al. 2004) found that baculum length is linked to mating behaviour (prolonged intromission) in primates, carnivores and pinnipeds and mammals in general. To our knowledge, no such hypothesis has yet been tested for raccoons explicitly, but the curved shape might suggest its role to be reinforcing stimulation rather than facilitating penetration. In order to further resolve these questions, a closer examination of the bone's biomechanics could be insightful. Though, they will not be answered satisfactorily without addressing the other half – the female side – as well, be it for raccoons or any other species.

Zusammenfassung

Morphometrische Charakterisierung einer Waschbärenpopulation aus dem Müritz-Nationalpark anhand des Os baculum

Die vorliegende Studie an der Waschbär-Population im Müritz-Nationalpark hat zum Ziel, frühere Ergebnisse zu bestätigen, wonach Gewicht und Länge des Os baculum (Penisknochen) dazu verwendet werden können, Waschbären in Altersgruppen einzuteilen. Des Weiteren werden – basierend auf der Messung verschiedener Knochenabschnitte sowie unter Einbezug von Alter, Hinterfusslänge und Gewicht der Hoden – allfällige allometrische Zusammenhänge untersucht. Daneben werden zwei verschiedene Messmethoden (klassisch mittels Schublehre und digital mittels des Programms ImageJ) angewandt und auf deren Tauglichkeit für diese Anwendung hin verglichen.

Die Resultate zeigen, dass es auch bei der Waschbär-Population aus dem Müritz-Nationalpark möglich ist, juvenile und adulte Tiere aufgrund des Gewichts, der Länge und der Verknöcherung des distalen Endes des Os baculum zu unterscheiden. Eine Aufteilung in weitere Altersklassen erscheint jedoch nicht möglich zu sein. Zusätzlich konnte bestätigt werden, dass der Knochen bei einer Länge um 100 mm ein Maximum erreicht, während sein Gewicht mit zunehmendem Alter weiterhin ansteigt. Vergleichbar dazu erreicht auch die Breite des distalen Köpfchens um 7.25 mm ein Maximum. Im Gegensatz dazu steht die Dicke des Knochenschaftes und insbesondere des proximalen Endes des Knochens, an dem dieser mit der Muskulatur verwachsen ist. Hier scheint sich das Dickenwachstum auch nach Erreichen des Knochenlängen-Maximums fortzusetzen. Grund hierfür könnte mechanische Belastung während des Paarungsaktes sein. Die meisten gemessenen Dimensionen des Knochens wachsen mehr oder weniger in Relation zum Längenwachstum, die Spannweite der distalen Krümmung jedoch bleibt beinahe konstant und wird dementsprechend relativ zur Länge gesehen mit zunehmendem Wachstum des Knochens geringer.

Der Vergleich der klassischen und digitalen Messmethode zeigt, dass beide Vorgehensweisen relativ präzise Resultate liefern, je nach Kontext aber dennoch jeweils ihre Vor- und Nachteile haben.

Zusammenfassend kann gesagt werden, dass die Erhebung von Gewicht, Länge und distaler Verknöcherung des Os baculum eine vergleichsweise einfache Methode darstellt, um Waschbären zuverlässig in juvenile und adulte Individuen einzuteilen. Die Entwicklung der Proportionen des Knochens legt nahe, dass seine Form entscheidend für seine Funktion ist. Die selektiven Kräfte, die zu eben dieser Form führten, dürften in Zusammenhang mit der mechanischen Interaktion mit den weiblichen Geschlechtsorganen stehen.

Summary

The present study on the raccoon population in Müritz National Park aims at confirming previous findings on the use of weight and length of the Os baculum (penis bone) to classify raccoons into age cohorts. Further, allometric relationships are investigated, based on a number of measured parts of the bone and incorporating age, hind foot length and testicles weight. Apart of that, two different measuring methods (classical using a sliding-calliper and digital using the programme ImageJ) are applied and compared for their suitability for such a task.

The results suggest that also for the raccoon population in Müritz National Park it is possible to distinguish juveniles and adults using weight, length and distal ossification of the Os baculum. However, a further division into other age classes does not seem to be possible. Additionally, it could also be confirmed that the length of the bone reaches a maximum at around 100 mm whilst its weight continues to increase with age. A similar maximum was found for the width of the distal head, which stops growing at around 7.25 mm. Different to that, the thickness of the bone's shaft and especially the proximal end, where the bone is connected to musculature, continues its growth.

The cause for this could possibly be mechanical stress during copulation. Most assessed dimensions of the bone increased more or less in relation with the increase of length, however, the reach of the distal curvature remains almost constant and accordingly decreases relative to length, the further the bone grows.
The comparison of the classical and digital measuring techniques indicates that both yield accurate results. Still both have their advantages and limitations depending on the context.
In conclusion, weight, length and distal ossification of the Os baculum provide comparatively easy assessable age estimates for raccoons, which reliably separate juveniles from adults. The way the bone's dimensions develop suggests its proportions to be crucial to its function. The selective forces that shaped it assumedly are associated with its mechanical interaction with the female reproductive organs.

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Anschriften der Verfasser:

BSc Orlando Schwery*
E-Mail: orlando.schwery@access.uzh.ch

Priv.-Doz. Dr. Winand Brinkmann
E-Mail: wbrink@pim.uzh.ch

Universität Zürich
Paläontologisches Institut und Museum
Karl-Schmid-Straße 4
CH-8006 Zürich

Dipl.-Biol. Berit A. Köhnemann*
E-Mail: koehnemann@projekt-waschbaer.de

Dipl.-Biol. Frank-Uwe Michler*
E-Mail: michler@projekt-waschbaer.de

Technische Universität Dresden
Institut für Forstzoologie
Arbeitsgruppe Wildtierforschung Tharandt
Pienner Straße 7
D-01737 Tharandt

*Forschungsstation „Projekt Waschbär"
Goldenbaum 38
D-17237 Carpin
Tel.: +49 (0) 39821-41382
Fax: +49 (0) 39821-41539
E-Mail: info@projekt-waschbaer.de
www.projekt-waschbaer.de