Postcranial differences in sex and species of pine marten (Martes martes L., 1758) and beech marten (Martes foina Erxl., 1777)

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Postcranial differences in sex and species of pine marten (*Martes martes* L., 1758) and beech marten (*Martes foina* Erxl., 1777)

Chris Baumann & Karolin Gornetzki

Abstract

To distinguish two closely related species, like the pine marten (*Martes martes*) and the beech marten (*Martes foina*), most scientists use the cranial features. The aim of this paper was to define other characteristic, morphological and metric sections to determine both sex and species of the German martens. For these we used measurable postcranial sections, which also were suitably found in archeological sites. Our analysis indicated that some morphological traits on atlas and scapula are useful to divide between beech marten and pine marten. To distinguish sexes, the metric analysis of the long bones and the pelvis gave good results.

Keywords: Morphology, Metric analysis, *Martes martes*, *Martes foina*, Postcranial.

1. Introduction

The genus *Martes* is a widespread taxa of small sized carnivores. Species of this genus inhabit both cold areas of the Holarctic and (sub-)tropical forest of the Indomalaya ecozone. Some of the species, like the beech marten, are actually synanthropic. In the Palearctic ecozone four species of *Martes* are found: *M. foina*, *M. martes*, *M. zibellina* and *M. melampus*. The first two species also exist in Germany (Stubbe 1993a). From a palaeontological view, the genus *Martes* is known since the Early Miocene (Burdigalian). The first evidence of pine marten, *M. martes*, is from the Late Pleistocene (Eemian and Würm glaciation) of Central and Western Europe. Also detected from the Late Pleistocene is *M. foina*, the beech marten, however, the first evidence for this species came from the Middle East (Anderson 1970). During the Würm glaciation, both *Martes* species populated Western Europe. Despite the long coexistence of these two closely related species, there was no hybridization observable (Stubbe 1993b). Therefore, from a Late Pleistocene site to a modern collection of Recent skeletons, we found bones of pine marten and beech marten – and there was the question: How could these species to be distinguished? Many authors have described differences based on colour of the fur, length of ears, tail or the whole body (e.g., Gaffrey 1961; Ansorge 1988; Stubbe 1993a-c). Another common method is to describe the skull and to find differences in the dental morphology. Stubbe (1993a) explained two major differences between *M. martes* and *M. foina* in the upper jaw: The buccal shape of the third premolar (P3) is in *M. martes* concave and in *M. foina* convex. Additionally, the first molar (M1) is monolobed in *M. martes* while it is bilobed in *M. foina*. There are also some other features at the skull and the lower jaw which could be used for a determination of species (Stubbe 1993a). However, in many cases collections lack skulls and, in other cases, excavators may find only single bones of a marten-like animal. Some authors described a morphological determination of the postcranial based on pictures and a few measured values (e.g., Pales & Vambert 1971; Schmid 1992; Grundbacher 1992; Stubbe 1993a-c). Ambros & Hilpert (2005) investigated marten bones from an archaeological cave context and described morphological and metric differences of these two species. Because some features were not visible in some Recent martens (e.g., some structure traits of the fibula), we addressed this issue in a previous study, which identified more diagnostic features (Baumann & Gornetzki 2013). In the present study, more individuals were measured, completed our previous measurements with the ones of Von den Driesch (1976) and additionally included a sexual determination. For this, we choose to analyze nine bones: Atlas, axis, scapula, humerus, radius, ulna, pelvis, baculum, tibia and femur, because the single bones were easy to determine (especially in an archaeological or palaeontological site), the measured sections were clearly definable and the individual variation was much lower than in other vertebras, ribs, tarsal or carpal bones.

Acknowledgements

We want to thank for providing the skeleton material the ZNS Halle (Zentralmagazin für Naturwissenschaftliche Sammlungen), especially Karla Schneider and Frank Steinheimer, the zoological and zooarchaeological collection of the University of Tübingen, especially Britt Starkovich, Susanne Münzel, Erich Weber, Jürgen Rössinger, and Angel Blanco Lapaz, the zoological collection of the University of Jena, especially Matthias Krüger and the Natural History Museum of Erfurt, especially Ulrich Scheidt and Marco Fischer. In addition, we are thankful to the taxidermists, which sent us the marten bodies for preparing, especially Annette Rode-Weingarten, Peter Mildner and Franz Müller. For reviewing, correcting mistakes and useful comments we like to express our thanks to Matthias Zink, Sara Rhodes, Viatcheslav Gasilin (Yekaterinburg) and an anonymous referee.

2. Material and methods

The sample used for our analysis includes 8 female skeletons and 19 male individuals of pine martens. To examine beech martens, 26 female skeletons and 43 male skeletons were analyzed. Unfortunately, it was not possible to take all measurements on the same individuals. In Table 1 the distribution of the measured skeleton elements is listed. The analyzed material belongs to several institutes, collections and museums of Germany as shown in Table 2. Around half of the material were from the Zentralmagazin für Naturwissenschaftliche Sammlungen (ZNS). This central collection is part of the Martin Luther University of Halle-Wittenberg and includes well-documented faunal remains from the last 150 years throughout different parts of Germany. Twenty-three individuals came from the Zoological Collection of the Eberhard Karls University of Tübingen. These skeletons were collected mainly from areas surrounding Tübingen and Stuttgart during the last 50 years. In addition, 10 individuals from the Zooarchaeological collection at Tuebingen University were examined. The remaining skeletons were from the Phyletic Museum of the Friedrich Schiller University of Jena, the Natural History Museum of Erfurt and from different taxidermists. The remaining skeletons are part of the author's private collection (C.B.).

The metric analysis was based on measurements from Von den Driesch (1976). In combination with her measurements, we defined some additional metrics (Baumann & Gornetzki 2013), as shown in Table 3. All measurements were taken with a digital sliding caliper to the nearest 0.01 mm. Each given value is the mean of three measurements. For bones, we measured both sides; we used the average of both means (left and right bone). Therefore, we got one value for each individual, each element and each measured section. Tables 4–13 show the descriptive statistical values of the samples. We calculated mean, minimum, maximum, median, standard deviation (SD), standard error (SE) and coefficient of variation (CV) as well as the t-test by using JMP 11 and Microsoft Excel 2016. For images, the DAVID Structure Light 3D Scanner SLS-1 was used and the programs MeshLab and Adobe Photoshop CS3, as well. Figs. 1, 4 and 8 show the atlas, axis and scapula of the female *Martes foina* 69/285 (ZNS Halle) and the male *Martes martes* 60/117 (ZNS Halle). The sexual differences in these elements were only recognized in the metrical values but not in the morphological traits. Therefore, the sexual differences should not influence the interpretation of the morphological features of the two species. We used the female beech marten and the male pine marten to show the most extreme size differences.

3. Results

The shape of the atlas was the clearest indicator to determine the two marten species. For *M. martes* both Processus transversales were approximately parallel, while in *M. foina* these Processus were tapered cranially, as shown in Fig. 1 (Ambros & Hilpert 2005; Baumann & Gornetzki 2013). The sexual dimorphism is shown in the cluster diagrams (Figs. 2, 3) and Table 4. Male individuals had larger GL and GB values than the females. For *M. foina* the males had values higher than 31.00 mm in the breadth of the wings (GB) and higher than 15.50 mm in the length (GL). Female individuals of *M. martes* were clearly smaller than 30.00 mm in their wings breadth.

For the axis, the breadth of the Processus spinosus inferior of *M. martes* is nearly flat, in contrast to *M. foina*, where this Processus is markedly thickened, as shown in Fig. 4 (Baumann & Gornetzki 2013). The values of LPs (Length of the Processus spinosus) and LPa (Length of the Pediculus arcus vertebralis) has been proven as significant for the differentiation of both sexes (Table 5). Fig. 5 shows the distribution of the LPa and LPs values of the pine marten. The LPs of females showed sizes until 21.00 mm, while the male values were higher than 19.50 mm. For the LPa, females had maximal 6.50 mm and the values of male individuals ranged between 6.00 mm and 7.50 mm. Fig. 6 shows the distribution of the LPa and LPs values of the beech marten. Below of 5.60 mm length there is a clear identification for females through the LPa values. Males were well determined with LPs values higher than 19.00 mm. Higher LPa and lower LPs values indicated an overlapping zone of both sexes. Fig. 7 shows the index of BPs (Breadth of the inferior Processus spinosus) and LPs of both species. With these values, it was possible to distinguish the species. Pine martens had lower values in BPs, but higher values in LPs in comparison to the beech martens.

In the scapula, the shape of the metacromion is long and small in *M. martes*. In contrast to these, *M. foina* is significant thicker, as shown in Fig. 8 (Belan 1975; Baumann & Gornetzki 2013). Additionally, this morphological aspect was represented in the metric values (Fig. 11). Between 6.00 mm and 7.00 mm was an overlapping zone. Below this zone, beech marten were clearly identifiable. The pine martin showed higher values in length. The index of B and L distinguished female from male marten, as shown in Figs. 9, 10 and Table 6. In *M. martes* the border between the sexes is at a length of 44.00 mm. More difficult was the beech marten. The differential line was at 45.00 mm in length, but there were some male individuals, which fell in the range of the females. The length of the metacromion was also an excellent metric indicator of species identification.

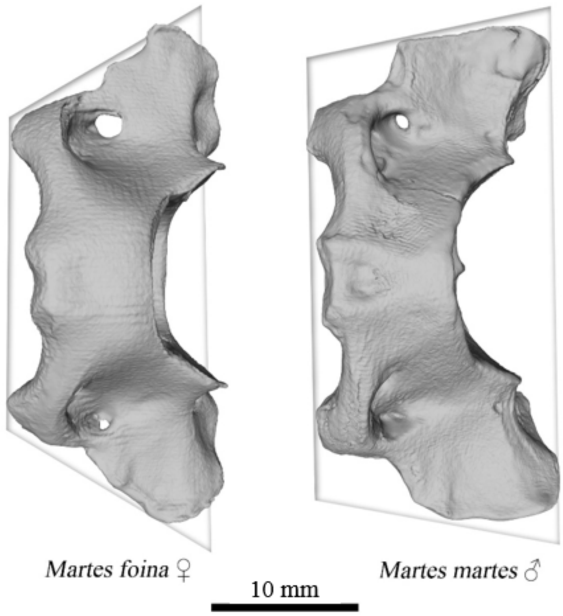

Fig. 1. Dorsal view of the atlas (turned 45° counterclockwise). In *Martes foina* the outlines show the trapezoidal shape of both Processus transversales, while in *Martes martes* the outlines reveal a greater parallelism of these processes.

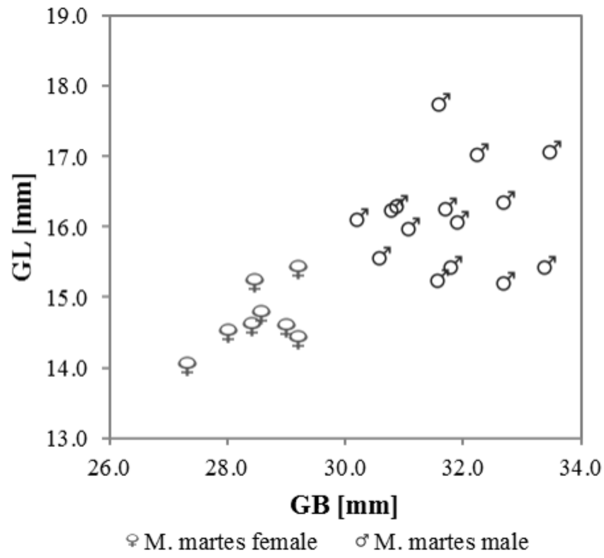

Fig. 3. Scatterplot of the greatest length (GL) and the greatest breadth over the wings (GB) of the atlas of male and female *Martes foina*. The grey zone shows the overlapping area of both sexes. The values of GL (t-test t = 7.99, df = 60, p < 0.0001) and GB (t-test t = 9.52, df = 59, p < 0.0001) differed significantly between males and females.

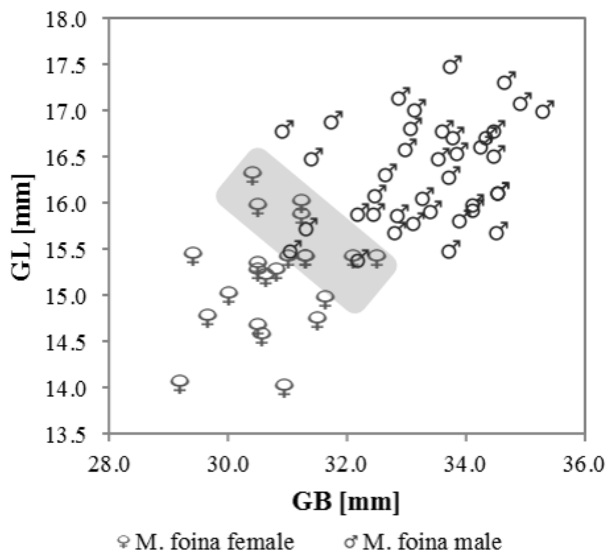

Fig. 2. Scatterplot of the greatest length (GL) and the greatest breadth over the wings (GB) of the atlas of male and female *Martes martes*. The values of GL (t-test t = 5.24, df = 21, p < 0.0001) and GB (t-test t = 8.44, df = 21, p < 0.0001) differed significantly between males and females.

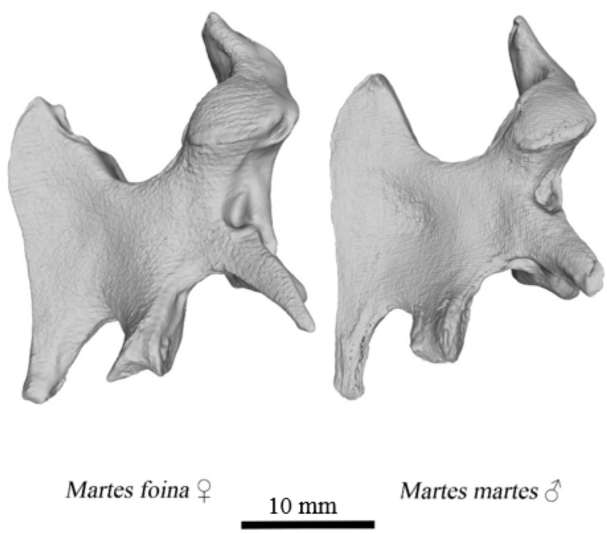

Fig. 4. Lateral view of the axis (cranial on the top) of *Martes foina* and *Martes martes*. At the Fig. 4 it is unclear which differences between bone of *Martes foina* and bone of *Martes martes* are emphasized.

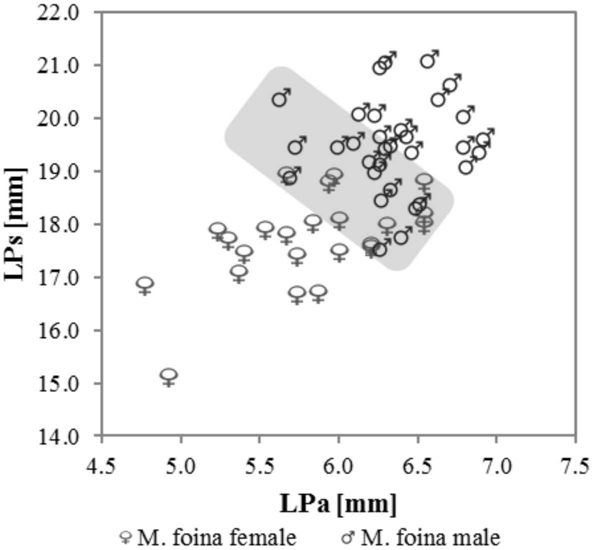

Fig. 5. Scatterplot of the length of the Processus spinosus (LPs) and the length of the Pediculus arcus vertebralis (LPa) of the axis of male and female *Martes martes*. The values of LPs (t-test t = 5.31, df = 19, $p < 0.0001$) and LPa (t-test t = 4.19, df = 19, p = 0.0005) differed significantly between males and females.

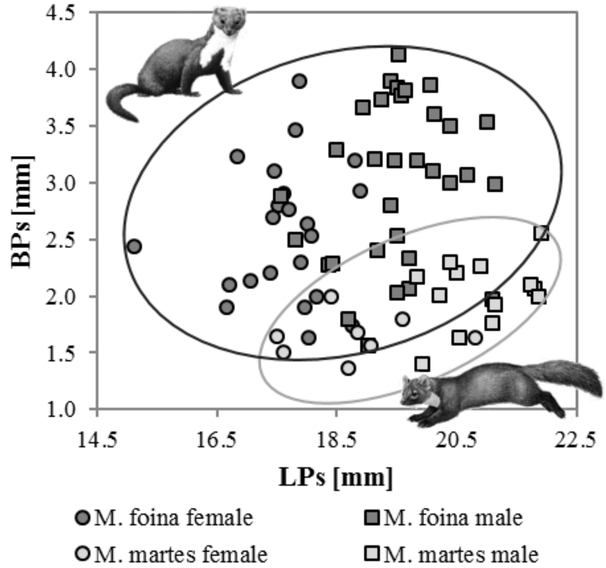

Fig. 7. Scatterplot of the breadth of the inferior Processus spinosus (BPs) and the length of the Processus spinosus (LPs) of the axis of *Martes foina* and *Martes martes* in both sexes. The grey outline shows the distribution of *Martes martes*, while the black outline shows the distribution of *Martes foina*. The values of BPs (t-test t = 6.00, df = 74, $p < 0.0001$) and LPs (t-test t = 4.14, df = 74, $p < 0.0001$) differed significantly between both species.

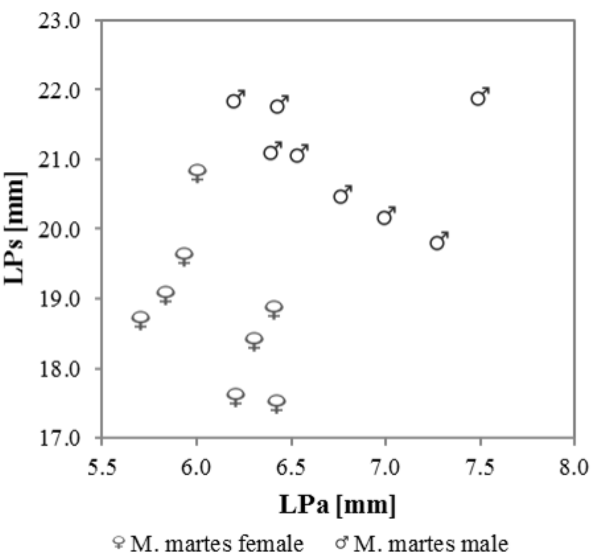

Fig. 6. Scatterplot of the length of the Processus spinosus (LPs) and the length of the Pediculus arcus vertebralis (LPa) of the axis of male and female *Martes foina*. The grey zone shows the overlapping area of both sexes. The values of LPs (t-test t = 7.77, df = 53, $p < 0.0001$) and LPa (t-test t = 5.20, df = 53, $p < 0.0001$) differed significantly between males and females.

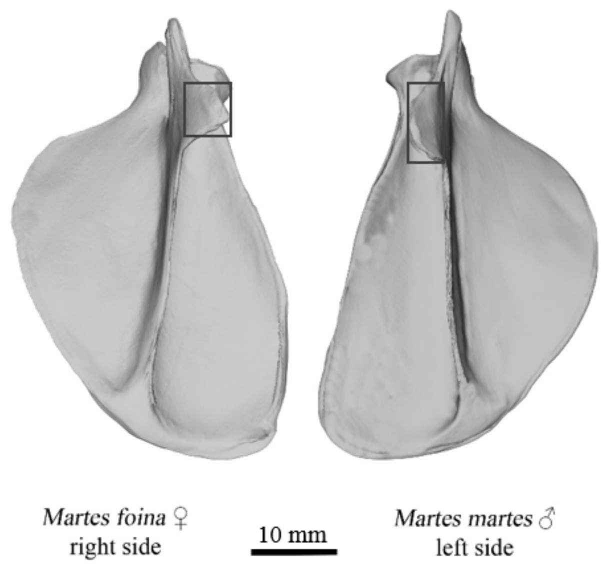

Fig. 8. Ventral view of the scapula (proximal on the top). The outlines show, that in *Martes foina* the metacromion is roughly quadratic, while in *Martes martes* this process is longer than and not as high as found in *Martes foina*.

For the humerus, the two measured distances, GL and Bd (Distal breadth), were important. In *M. martes* the differentiation line between male and female in the values of Bd was at 14.00 mm. The values of GL showed an overlapping zone in the range of 70.00 mm. The sexes of *M. foina* were clearly identifiable using GL value. There was only a thin overlapping zone in the range of 66.00 mm. The scatterplot (Fig. 12) and Table 7 also shows the distribution of the species.

To divide the sexes of both marten species, the greatest length (GL) of the radius was a superior indicator (Fig. 13, Table 8). The dividing line of *M. martes* was at 55.00 mm and of *M. foina* at 50.50 mm. Above these values the individuals were clearly male and below these values they were female. Similar to the radius, the GL values of the ulna differentiated males and females of both species (Table 9).

The GL-LO-cluster of the ulna of *M. martes* is shown in Fig. 14. At 66.10 mm was the dividing line – higher values in GL identify males, lower values females. For *M. foina*, Fig. 15 shows this distribution. Here the line was at 63.00 mm.

The cluster diagrams (Figs. 16, 17) show the distribution of the length (GL) and breadth (GB) values of the pelvis. In the both species, females showed low values and males high values (Table 10). Therefore, female *M. martes* showed GB values less than 27.60 mm and GL values less than 58.00 mm. Female *M. foina* showed GB values less than 30.00 mm and GL values less than 58.00 mm.

For both species, higher values identified male individuals. The (morphological) presence of a baculum in mustelids was a very strong argument to include a male individual. The Index from GL and GB was a good marker to differentiate the species (Table 11). Fig. 18 shows a clear border between both marten species. *M. martes* showed lower values (less than 45.50 mm) than *M. foina* (more than 45.00 mm).

The distribution of the breadth of the Caput (Bcap) and the distal breadth (Bd) of the femur is shown in Figs. 19, 20 and Table 12. In *M. martes* there was a clear line in the Bd values between males and females at 13.70 mm. *Martes foina* showed a large overlapping zone between 13.90 mm and 14.50 mm in the Bd values.

In Table 13, the descriptive statistic of the tibia is shown. The values do not differ strongly enough to distinguish species or sexes.

4. Discussion

As shown in Table 1, the number of individuals used for our analysis in species and sex differed. One goal of our previous study was to make a morphometric analysis of 15–20 individuals of each species and sex. However, collection of the desired number of individuals was not possible as only few institutions in Germany collected complete skeletons of these species. In addition, not every individual was a complete skeleton. In some cases, the collectors had only the skulls and some bones, like baculum, pelvis or atlas or the skeletons suffered the drawback of incomplete maceration resulting in connective tissue covering the important measuring points. In addition, some skeletons were mounted and dismantled in parts, which substantially hindered the measurement of all bones of the given individuals. As desired number of individuals could not be collected, analysis of juvenile and subadult individuals was not possible.

In Fig. 21, the locations of the collected martens by the different institutes were shown. We attempted to use different marten populations in Germany to find differences that exemplified the south as well as for the north of the country. A hypothesis of our previous study (Baumann & Gornetzki 2013) was that populations of widespread species, like *M. foina*, showed morphological or metrical differences in the skeleton dependent on region. However, for the both marten species we did not find such differences at the population level. The individual differences were larger than differences between north and south.

On a morphological point of view of the species determination, the shape of the atlas (Fig. 1), the breadth of the Processus spinosus inferior of the axis, the shape of the metacromion of the scapula (Fig. 8) and the shape and length of the baculum were the most characteristic features. The metrical analysis showed in most cases a distribution of the sexes. Though, in the clusters of the axis (Fig. 7), humerus (Fig. 12) and the baculum (Fig. 18) and the both range diagrams (Figs. 11, 13) of scapula and radius, a distinction on species level was possible. As already mentioned above, the bulk of existing literature deals with cranial features to determine both marten species, but it was also possible to find differences in the postcranial. Morphological differences in the shape of the atlas were also recognized and analyzed by other authors (Stubbe 1993a; Ambros & Hilpert 2005; Baumann & Gornetzki 2013). The parallelism of the Processus articulares in *M. martes* and the trapeze-like shape in *M. foina* was one of the best postcranial features to determine the two species. Also on the second vertebra, the axis, were recognizable and measurable markers for species determination. The inferior part of the spine was different in both martens – in pine martens, it was already flat, while in beech martens this part shows, mostly, a bulge. The variability of this feature in *M. foina* is very high, but most of them showed a bulge larger than two millimeters. However, the pine martens mostly showed values lower than two millimeters. Another feature, Stubbe (1993a) used for a differential diagnosis, was the shape of the scapula. In our analysis, we did not use this shape because the variability

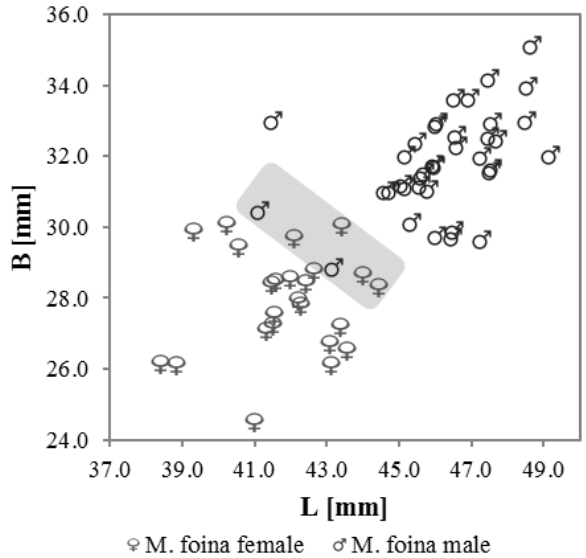

Fig. 9. Scatterplot of the greatest length (L) and the greatest breadth (B) of the scapula of male and female *Martes martes*. The grey zone shows the overlapping of the both sexes. The values of L (t-test t = 7.79, df = 21, $p < 0.0001$) and B (t-test t = 4.13, df = 21, p = 0.0002) differed significantly between males and females.

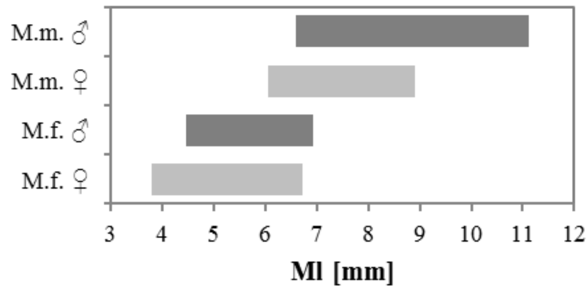

Fig. 11. Diagram of the range of lengths of the metacromion (Ml) of the scapula of male and female *Martes martes* (M.m.) and *Martes foina* (M.f.). The value of Ml (t-test t = 13.59, df = 82, $p < 0.0001$) differed significantly between both species.

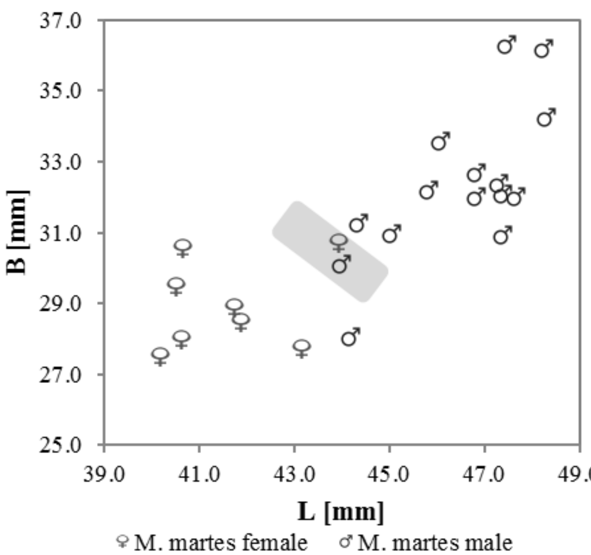

Fig. 10. Scatterplot of the greatest length (L) and the greatest breadth (B) of the scapula of male and female *Martes foina*. The grey zone shows the overlapping of the both sexes. The values of L (t-test t = 9.94, df = 59, $p < 0.0001$) and B (t-test t = 10.73, df = 59, $p < 0.0001$) differed significantly between males and females.

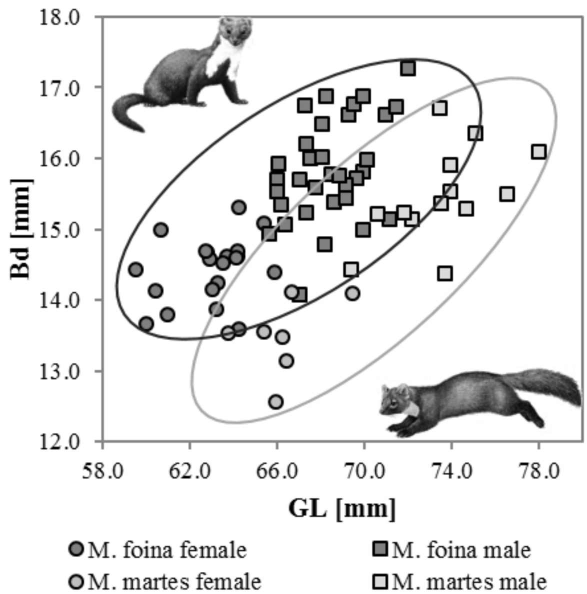

Fig. 12. Scatterplot of the greatest length (GL) and the distal breadth (Bd) of the humerus of *Martes foina* and *Martes martes* of both sexes. The grey outline shows the distribution of *Martes martes*, while the black outline shows the distribution of *Martes foina*. The values of GL (t-test t = 5.21, df = 74, $p < 0.0001$) and Bd (t-test t = 2.08, df = 74, p = 0.0409) differed significantly between both species.

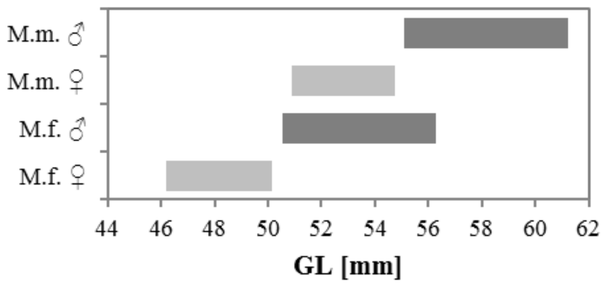

Fig. 13. Diagram of the range of the greatest length (GL) of the radius of male and female *Martes martes* (M.m.) and *Martes foina* (M.f.). The value of GL (t-test t = 5.99, df = 64, p < 0.0001) differed significantly between both species.

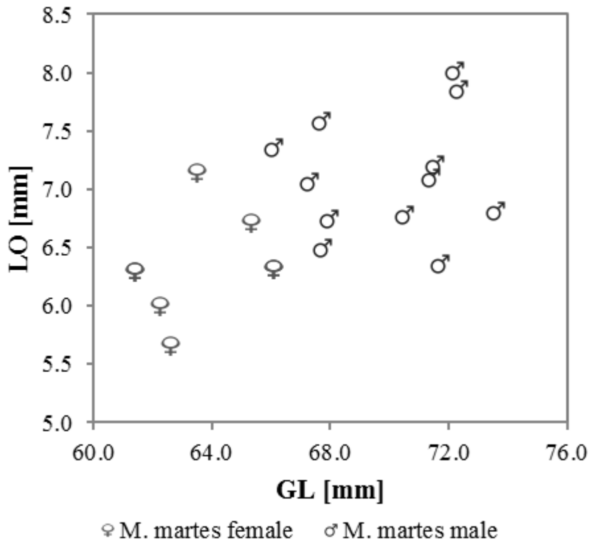

Fig. 15. Scatterplot of the length of the olecranon (LO) and the greatest length (GL) of the ulna of male and female *Martes foina*. The grey zone shows the overlapping of the both sexes. The values of LO (t-test t = 4.16, df = 46, p = 0.0001) and GL (t-test t = 7.71, df = 46, p < 0.0001) differed significantly between males and females.

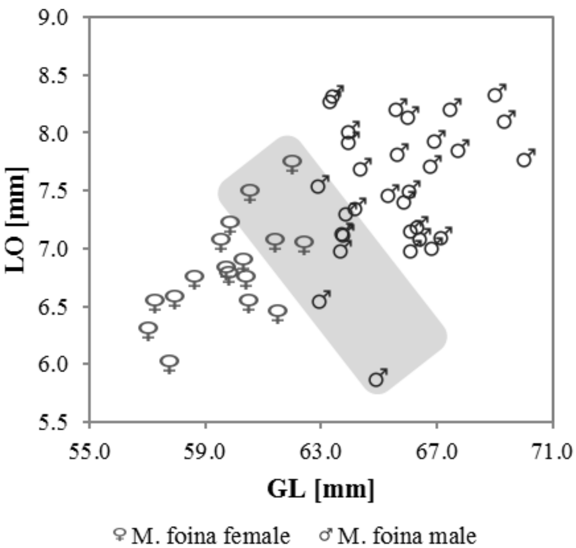

Fig. 14. Scatterplot of the length of the olecranon (LO) and the greatest length (GL) of the ulna of male and female *Martes martes*. The values of LO (t-test t = 3.09, df = 17, p = 0.0066) and GL (t-test t = 5.92, df = 17, p < 0.0001) differed significantly between males and females.

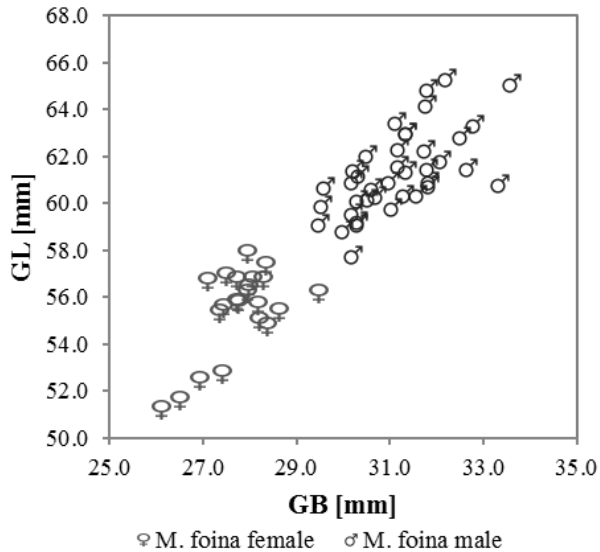

Fig. 16. Scatterplot of the greatest length (GL) and the greatest breadth (GB) of the pelvis of male and female *Martes martes*. The values of GL (t-test t = 8.75, df = 21, p < 0.0001) and GB (t-test t = 7.80, df = 21, p < 0.0001) differed significantly between males and females.

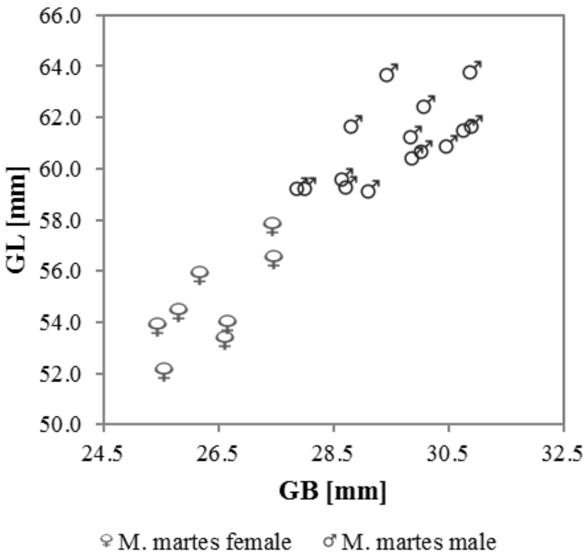

Fig. 17. Scatterplot of the greatest length (GL) and the greatest breadth (GB) of the pelvis of male and female *Martes foina*. The values of GL (t-test t = 9.76, df = 59, $p < 0.0001$) and GB (t-test t = 10.27, df = 59, $p < 0.0001$) differed significantly between males and females.

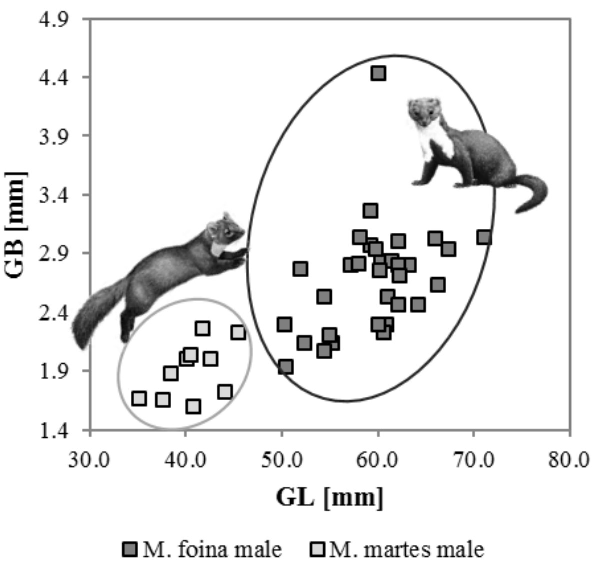

Fig. 18. Scatterplot of the greatest breadth (GB) and the greatest length (GL) of the baculum of male *Martes foina* and *Martes martes*. The grey outline shows the distribution of *Martes martes*, while the black outline shows the distribution of *Martes foina*. The values of GB (t-test t = 4.84, df = 38, $p < 0.0001$) and GL (t-test t = 12.47, df = 38, $p < 0.0001$) differed significantly between both species.

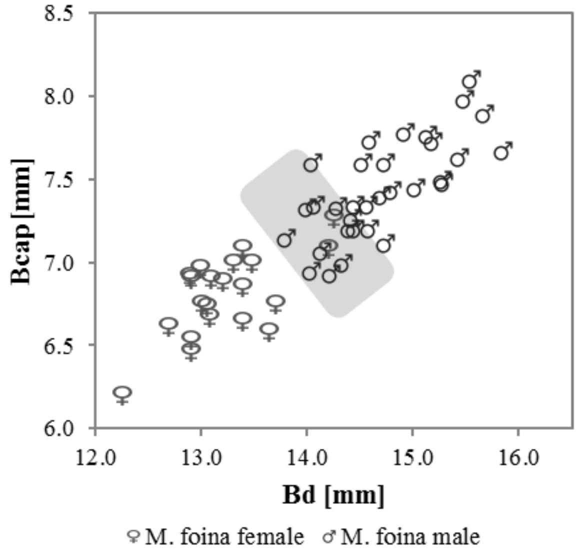

Fig. 19. Scatterplot of the breadth of the Caput femoris (Bcap) and the distal breadth (Bd) of the femur of male and female *Martes martes*. The values of Bcap (t-test t = 4.30, df = 19, p = 0.0004) and Bd (t-test t = 8.40, df = 19, $p < 0.0001$) differed significantly between males and females.

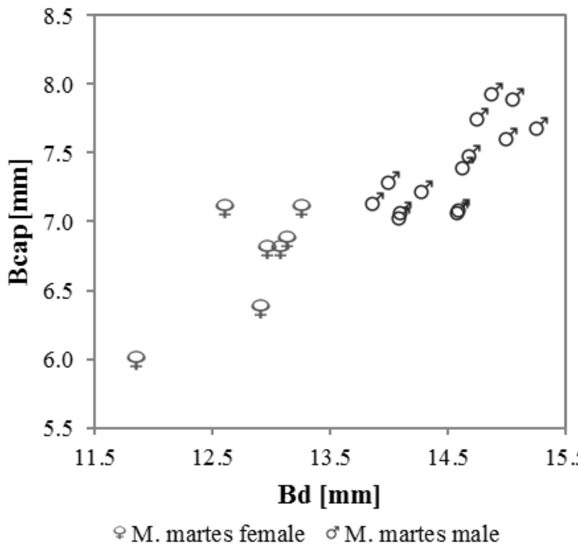

Fig. 20. Scatterplot of the breadth of the Caput femoris (Bcap) and the distal breadth (Bd) of the femur of male and female *Martes foina*. The grey zone shows the overlapping area of both sexes. The values of Bcap (t-test t = 5.70, df = 52, $p < 0.0001$) and Bd (t-test t = 6.74, df = 52, $p < 0.0001$) differed significantly between males and females.

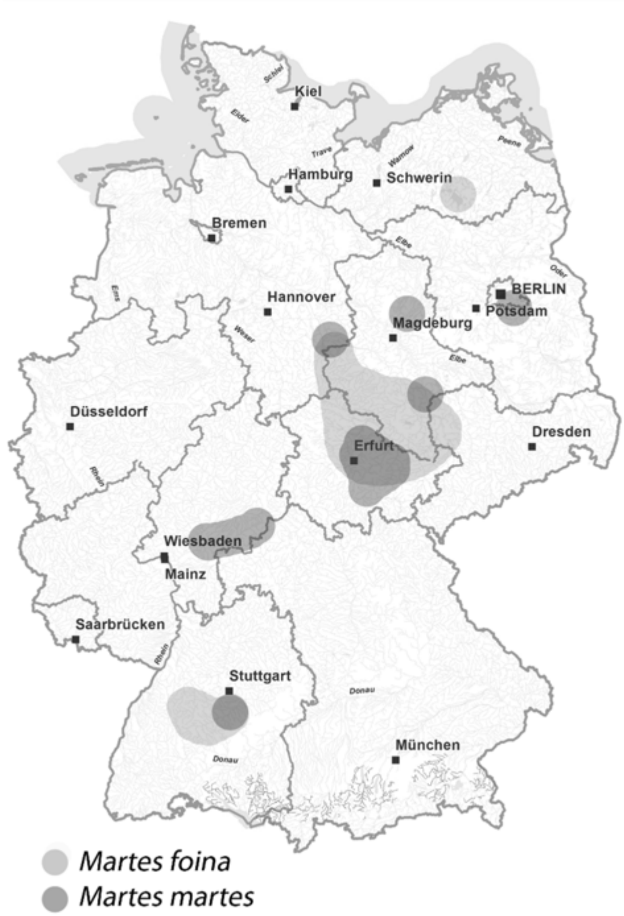

Fig. 21. Map of the location of analyzed martens from the diverse collections used in this paper.

between the species was not high enough to see such different shapes. A better trait was the shape of the metacromion. Especially the length was a good indicator for the species. A value lower than six millimeters was beech marten and higher than seven millimeters could be attributed to pine marten. Also in the long bones, there were metrical features that allowed distinguishing between *M. foina* and *M. martes*. The clearest indication was shown in the humerus. Pine marten had higher GL values than beech marten, but lower values in the distal breadth (Bd). For humerus, it meant, that the values of GL in beech marten were 5–8 % lower than in pine marten, but the Bd values were 2–7 % higher. The same phenomenon was shown in other long bones but was not as prominent. For the femur, *M. foina* had a 3–6 % lower GL value and a 1–5 % higher Bd value than *M. martes*. In the radius, values in GL of beech martens were 10 % lower than in pine marten, but the Bd value were the same. One of the clearest metrical differences between the two species was the length and breadth of the baculum. Because of the sexual selection of species, a large selection pressure was recognizable on this bone. Therefore, a high variation in metrical values between two closely related species was conceivable. In *M. martes* and *M. foina*, the highest variation of 32 % was in the baculum. The male beech marten had a GL value 32 % higher and a GB value 29 % higher than the pine marten. The maximum size of our measured pine martens was 45.46 mm and the minimum size of the beech martens was 50.40 mm. Therefore, this bone was not only a good marker for a sexual determination, but also for a species determination. In some cases, this bone was missing and the individual was determined as female – only by the absence of the baculum. Nevertheless, not only the baculum could provide information about the sex.

The metrical analysis of sexes based on the differences in size of the male and female martens. These differences were shown in the scapula and all long bones, more specifically the humerus, radius, ulna and femur. The most important value was the greatest length (GL). In all analyzed bones, this value was lower in females and higher in males. Both martens, *M. foina* and *M. martes*, showed a recognizable sexual dimorphism. Male pine martens weighed approximately 400 g more than females, in beech martens the difference was 350 g (König & Müller 1986a, b). This dimorphism was also recognizable in bones. The measurements of the skull (e.g., condylobasal length) also showed higher values in males and lower in females (Ansorge 1988; Douma-Petridou 1984). The same ratio was recognizable in the postcranial. The smaller females had also smaller values in the length of the long bones. In general, the measured sections of long bones showed that female beech martens were 7–10 % smaller than males and female pine martens were 9–12 % smaller than male individuals. The values of the distal breadth (Bd) of the femur was an excellent marker too. Beech marten females had 9 % and pine marten females 14 % lower values than the males of the same species. This sexual size dimorphism was also shown in other bones. Both relevant values of the atlas, the greatest breadth over the wings (GB) and the greatest length (GL), shown lower sizes in females and higher in males. This difference in beech martens was 8 % and in pine martens between 10 % and 12 % of both values. The LPa values of the axis was also a good indicator for sexual determination. The length of the Pediculus arcus vertebralis (LPa) was in female beech martens and pine martens 10–11% smaller than in males. In most mammals, the best indicator for sexes is the pelvis. Also for the both marten species, the GL and GB values were a superior tracer. The difference between males and females was in both species about 11–12 % in both values. In Figs. 17 and 18 is also shown, that there was no overlapping zone – even in the high number of beech martens. Therefore, the pelvis was the best postcranial element for a metrical sex determination.

5. Conclusions

As shown in this study, a determination sex and species of *Martes martes* and *Martes foina* using the postcranial skeleton is possible. To distinguish *Martes martes* from *Martes foina*, not only features from skull and teeth are important. In addition, the shape of the atlas or the length of the baculum gave clear evidence of the species. In combination with the metrical analysis of the long bones and the vertebrae, the postcranial skeleton showed enough traits to determinate the martens without the skull. Pine marten has longer and narrower limbs than beech marten. Not only through the presence of the baculum can sex be assigned. Also with the length and breadth of the pelvis a clear differentiation between males and females is possible. Furthermore, the metrical analyses of the long bones and the vertebrae showed, that females were around 10 % smaller than males in both, beech marten and pine marten.

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Table 1: Number of analyzed individuals, divided in elements, species and sex.

	M. foina ♀	*M. foina* ♂	*M. martes* ♀	*M. martes* ♂
Atlas	23	39	8	15
Axis	23	32	8	13
Scapula	24	37	8	15
Humerus	21	35	7	13
Radius	16	31	7	12
Ulna	17	31	8	11
Pelvis	23	38	8	16
Baculum	-	32	-	10
Femur	23	31	7	14
Tibia	19	28	5	7
Individuals	26	43	8	19

Table 2: List of the Institutes, were the analyzed marten skeletons come from.

Istitution	**No. of individuals**
Zentralmagazin für Naturwissenschaftliche Sammlungen, Halle	43
Zoological Collection of the University of Tübingen	23
Zooarchaeological Collection of the University of Tübingen	10
Phyletic Museum of the University of Jena	10
Natural History Museum of Erfurt	5
Authors, private collection	5
Total:	**96**

Table 3: Measured sections and the both publications, were this sections are defined.

Element	**Mesured section**	**Abbreviation**	**Von den Driesch (1976)**	**Baumann & Gornetzki (2013)**
Atlas	Greatest breadth over the wings	GB	X	
Atlas	Greatest length	GL	X	
Axis	Length of the *Pediculus arcus* vertebralis	LPa		X
Axis	Length of the *Processus spinosus*	LPs		X
Axis	Breadth of the inferior *Processus spinosus*	BPs		X
Scapula	Greatest length	L	X	
Scapula	Greatest breadth	B		X
Scapula	Length of the metacromion	Ml		X
Humerus	Greatest length	GL	X	
Humerus	Distal breadth	Bd	X	
Ulna	Greatest length	GL	X	
Ulna	Length of the olecranon	LO	X	
Radius	Greatest length	GL	X	
Pelvis	Greatest length	GL	X	
Pelvis	Greatest breadth	GB		X
Baculum	Greatest length	GL		X
Baculum	Greatest breadth	GB		X
Femur	Greatest length	GL	X	
Femur	Distal breadth	Bd	X	
Femur	breadth of the *Caput femoris*	Bcap		X
Tibia	Greatest length	GL	X	
Tibia	Distal breadth	Bd	X	

Table 4: Descriptive statistics of the atlas, divided in species and sex. This table gives the values of the greatest breadth over the wings (GB) and the greatest length (GL), including number of individuals (n), mean value (mean), standard deviation (SD), minimum and maximum measured value (min and max), median value (median), standard error (SE) and coefficient of variation (CV).

	GB - n	GB - mean [mm]	GB - SD	GB - min [mm]	GB - max [mm]	GB - median [mm]	GB - SE	GB - CV
M. foina ♂	39	33.35	1.11	30.93	35.31	33.57	0.18	3.31
M. foina ♀	22	30.79	0.81	29.18	32.50	30.72	0.17	2.64
M. martes ♂	15	31.79	0.99	30.23	33.50	31.73	0.25	3.10
M. martes ♀	8	28.51	0.65	27.30	29.20	28.51	0.23	2.27
	GL - n	**GL - mean [mm]**	**GL - SD**	**GL - min [mm]**	**GL - max [mm]**	**GL - median [mm]**	**GL - SE**	**GL - CV**
M. foina ♂	39	16.36	0.55	15.40	17.50	16.33	0.09	3.38
M. foina ♀	23	15.17	0.59	14.00	16.30	15.27	0.12	3.88
M. martes ♂	15	16.17	0.73	15.23	17.78	16.13	0.19	4.50
M. martes ♀	8	14.69	0.44	14.03	15.40	14.59	0.16	3.00

Table 5: Descriptive statistics of the axis, divided in species and sex. This table gives the values of the length of the Pediculus arcus vertebralis (LPa), the length of the Processus spinosus (LPs) and the breadth of the inferior Processus spinosus (BPs), including number of individuals (n), mean value (mean), standard deviation (SD), minimum and maximum measured value (min and max), median value (median), standard error (SE) and coefficient of variation (CV).

	LPa - n	LPa - mean [mm]	LPa - SD	LPa - min [mm]	LPa - max [mm]	LPa - median [mm]	LPa - SE	LPa - CV
M. foina ♂	32	6.36	0.32	5.63	6.92	6.32	0.06	5.07
M. foina ♀	23	5.79	0.48	4.77	6.53	5.83	0.10	8.37
M. martes ♂	13	6.75	0.38	6.20	7.50	6.77	0.11	5.63
M. martes ♀	8	6.10	0.27	5.70	6.42	6.10	0.10	4.44
	LPs - n	**LPs - mean [mm]**	**LPs - SD**	**LPs - min [mm]**	**LPs - max [mm]**	**LPs - median [mm]**	**LPs - SE**	**LPs - CV**
M. foina ♂	32	19.52	0.87	17.57	21.14	19.50	0.15	4.45
M. foina ♀	23	17.68	0.86	15.12	18.93	17.80	0.18	4.84
M. martes ♂	13	20.91	0.75	19.83	21.92	20.90	0.21	3.57
M. martes ♀	8	18.81	1.07	17.49	20.80	18.77	0.38	5.70
	BPs - n	**BPs - mean [mm]**	**BPs - SD**	**BPs - min [mm]**	**BPs - max [mm]**	**BPs - median [mm]**	**BPs - SE**	**BPs - CV**
M. foina ♂	32	3.00	0.71	1.57	4.13	3.09	0.13	23.67
M. foina ♀	23	2.62	0.63	1.63	3.90	2.63	0.13	24.00
M. martes ♂	13	2.03	0.30	1.40	2.56	2.07	0.08	14.93
M. martes ♀	8	1.65	0.19	1.37	2.00	1.64	0.07	11.55

Table 6: Descriptive statistics of the scapula, divided in species and sex. This table gives the values of the greatest length (L), the greatest breadth (B) and the breadth of the lengths of the metacromion (Ml), including number of individuals (n), mean value (mean), standard deviation (SD), minimum and maximum measured value (min and max), median value (median), standard error (SE) and coefficient of variation (CV).

	L - n	**L - mean [mm]**	**L - SD**	**L - min [mm]**	**L - max [mm]**	**L - median [mm]**	**L - SE**	**L - CV**
M. foina ♂	37	46.18	1.73	41.13	49.18	46.05	0.28	3.75
M. foina ♀	24	41.83	1.57	38.38	44.42	42.02	0.32	3.75
M. martes ♂	15	46.45	1.46	43.98	48.28	46.82	0.38	3.15
M. martes ♀	8	41.57	1.37	40.15	43.92	41.18	0.48	3.29
	B - n	**B - mean [mm]**	**B - SD**	**B - min [mm]**	**B - max [mm]**	**B - median [mm]**	**B - SE**	**B - CV**
M. foina ♂	37	31.87	1.40	28.87	35.15	31.78	0.23	4.39
M. foina ♀	24	27.89	1.44	24.50	30.05	28.13	0.29	5.15
M. martes ♂	15	32.35	2.15	28.07	36.33	32.12	0.56	6.65
M. martes ♀	8	28.93	1.24	27.50	30.72	28.70	0.44	4.27
	Ml - n	**Ml - mean [mm]**	**Ml - SD**	**Ml- min [mm]**	**Ml - max [mm]**	**Ml - median [mm]**	**Ml - SE**	**Ml - CV**
M. foina ♂	37	5.56	0.60	4.47	6.92	5.61	0.10	10.71
M. foina ♀	24	4.89	0.69	3.78	6.72	4.93	0.14	14.18
M. martes ♂	15	8.58	1.12	6.60	11.11	8.42	0.29	13.06
M. martes ♀	8	7.47	1.06	6.05	8.90	7.56	0.37	14.15

Table 7: Descriptive statistics of the humerus, divided in species and sex. This table gives the values of the distal breadth (Bd) and the greatest length (GL), including number of individuals (n), mean value (mean), standard deviation (SD), minimum and maximum measured value (min and max), median value (median), standard error (SE) and coefficient of variation (CV).

	Bd - n	**Bd - mean [mm]**	**Bd - SD**	**Bd - min [mm]**	**Bd - max [mm]**	**Bd - median [mm]**	**Bd - SE**	**Bd - CV**
M. foina ♂	35	15.84	0.70	14.08	17.27	15.75	0.12	4.44
M. foina ♀	21	14.44	0.45	13.58	15.30	14.58	0.10	3.12
M. martes ♂	13	15.47	0.68	14.37	16.72	15.37	0.19	4.37
M. martes ♀	7	13.50	0.54	12.57	14.12	13.53	0.20	3.99
	GL - n	**GL - mean [mm]**	**GL - SD**	**GL - min [mm]**	**GL - max [mm]**	**GL - median [mm]**	**GL - SE**	**GL - CV**
M. foina ♂	35	68.42	1.67	65.64	72.00	68.25	0.28	2.44
M. foina ♀	21	63.00	1.74	59.53	65.87	63.27	0.38	2.76
M. martes ♂	13	73.59	2.29	69.40	77.97	73.67	0.64	3.12
M. martes ♀	7	66.26	1.70	63.77	69.43	66.25	0.64	2.57

Table 8: Descriptive statistics of the radius, divided in species and sex. This table gives the values of the greatest length (GL), including number of individuals (n), mean value (mean), standard deviation (SD), minimum and maximum measured value (min and max), median value (median), standard error (SE) and coefficient of variation (CV).

	GL - n	GL - mean [mm]	GL - SD	GL - min [mm]	GL - max [mm]	GL - median [mm]	GL - SE	GL - CV
M. foina ♂	31	53.01	1.58	50.53	56.30	53.03	0.28	2.99
M. foina ♀	16	48.22	1.33	46.17	50.17	48.14	0.33	2.76
M. martes ♂	12	58.12	2.11	55.10	61.23	59.03	0.61	3.62
M. martes ♀	7	52.64	1.35	50.90	54.75	52.60	0.51	2.56

Table 9: Descriptive statistics of the ulna, divided in species and sex. This table gives the values of the greatest length (GL) and the length of the *olecranon* (LO), including number of individuals (n), mean value (mean), standard deviation (SD), minimum and maximum measured value (min and max), median value (median), standard error (SE) and coefficient of variation (CV).

	GL - n	GL - mean [mm]	GL - SD	GL - min [mm]	GL - max [mm]	GL - median [mm]	GL - SE	GL - CV
M. foina ♂	31	65.51	1.73	62.93	69.38	65.70	0.31	2.64
M. foina ♀	17	60.28	2.97	56.98	70.08	59.85	0.72	4.93
M. martes ♂	11	69.82	2.45	66.08	73.58	70.48	0.74	3.51
M. martes ♀	8	63.56	1.99	61.38	66.07	63.02	0.70	3.14
	LO - n	**LO - mean [mm]**	**LO - SD**	**LO - min [mm]**	**LO - max [mm]**	**LO - median [mm]**	**LO - SE**	**LO - CV**
M. foina ♂	31	7.54	0.57	5.88	8.35	7.52	0.10	7.62
M. foina ♀	17	6.86	0.49	6.00	7.79	6.77	0.12	7.10
M. martes ♂	11	6.99	0.45	6.37	8.02	6.90	0.14	6.45
M. martes ♀	8	6.35	0.44	5.66	7.15	6.31	0.16	7.00

Table 10: Descriptive statistics of the pelvis, divided in species and sex. This table gives the values of the greatest length (GL) and the greatest breadth (GB), including number of individuals (n), mean value (mean), standard deviation (SD), minimum and maximum measured value (min and max), median value (median), standard error (SE) and coefficient of variation (CV).

	GL - n	GL - mean [mm]	GL - SD	GL - min [mm]	GL - max [mm]	GL - median [mm]	GL - SE	GL - CV
M. foina ♂	38	61.29	1.68	57.78	65.38	60.97	0.27	2.74
M. foina ♀	23	55.83	2.70	51.19	65.13	55.78	0.56	4.84
M. martes ♂	15	61.06	1.55	59.20	63.88	60.99	0.40	2.53
M. martes ♀	8	54.71	1.86	52.10	57.78	54.16	0.66	3.40
	GB - n	**GB - mean [mm]**	**GB - SD**	**GB - min [mm]**	**GB - max [mm]**	**GB - median [mm]**	**GB - SE**	**GB - CV**
M. foina ♂	38	31.11	0.95	29.49	33.33	31.15	0.15	3.04
M. foina ♀	23	28.01	1.41	26.11	33.59	27.93	0.29	5.04
M. martes ♂	15	29.58	1.00	27.90	30.92	29.86	0.26	3.39
M. martes ♀	8	26.38	0.79	25.43	27.45	26.38	0.28	3.00

Table 11: Descriptive statistics of the baculum, divided in species. This table gives the values of the greatest length (GL) and the greatest breadth (GB), including number of individuals (n), mean value (mean), standard deviation (SD), minimum and maximum measured value (min and max), median value (median), standard error (SE) and coefficient of variation (CV).

	GL - n	**GL - mean [mm]**	**GL - SD**	**GL - min [mm]**	**GL - max [mm]**	**GL - median [mm]**	**GL - SE**	**GL - CV**
M. foina ♂	32	59.60	4.87	50.33	71.07	60.18	0.86	8.17
M. martes ♂	10	40.63	3.08	35.10	45.46	40.64	0.98	7.59
	GB - n	**GB - mean [mm]**	**GB - SD**	**GB - min [mm]**	**GB - max [mm]**	**GB - median [mm]**	**GB - SE**	**GB - CV**
M. foina ♂	32	2.69	0.47	1.93	4.44	2.76	0.08	17.42
M. martes ♂	10	1.90	0.24	1.60	2.26	1.94	0.08	12.47

Table 12: Descriptive statistics of the femur, divided in species and sex. This table gives the values of the greatest length (GL), the distal breadth (Bd) and the breadth of the Caput femoris (Bcap), including number of individuals (n), mean value (mean), standard deviation (SD), minimum and maximum measured value (min and max), median value (median), standard error (SE) and coefficient of variation (CV).

	GL - n	**GL - mean [mm]**	**GL - SD**	**GL - min [mm]**	**GL - max [mm]**	**GL - median [mm]**	**GL - SE**	**GL - CV**
M. foina ♂	31	77.33	2.00	73.69	80.90	77.75	0.36	2.58
M. foina ♀	23	72.29	3.53	67.03	81.72	72.10	0.74	4.88
M. martes ♂	14	81.81	2.32	76.77	85.68	81.68	0.62	2.83
M. martes ♀	7	74.82	1.95	72.95	77.90	74.36	0.74	2.60
	Bd - n	**Bd - mean [mm]**	**Bd - SD**	**Bd - min [mm]**	**Bd - max [mm]**	**Bd - median [mm]**	**Bd - SE**	**Bd - CV**
M. foina ♂	31	14.68	0.52	13.80	15.84	14.58	0.09	3.56
M. foina ♀	23	13.43	0.83	12.25	15.66	13.20	0.17	6.21
M. martes ♂	14	14.56	0.43	13.87	15.27	14.62	0.12	2.96
M. martes ♀	7	12.82	0.48	11.85	13.25	12.96	0.18	3.72
	Bcap - n	**Bcap - mean [mm]**	**Bd - SD**	**Bcap - min [mm]**	**Bcap - max [mm]**	**Bcap - median [mm]**	**Bcap - SE**	**Bcap - CV**
M. foina ♂	31	7.43	0.29	6.93	8.10	7.40	0.05	3.93
M. foina ♀	23	6.90	0.39	6.20	7.90	6.88	0.08	5.71
M. martes ♂	14	7.42	0.32	7.04	7.95	7.36	0.09	4.36
M. martes ♀	7	6.72	0.40	6.00	7.10	6.80	0.15	5.97

Table 13: Descriptive statistics of the tibia, divided in species and sex. This table gives the values of the greatest length (GL) and the distal breadth (Bd), including number of individuals (n), mean value (mean), standard deviation (SD), minimum and maximum measured value (min and max), median value (median), standard error (SE) and coefficient of variation (CV).

	GL - n	GL - mean [mm]	GL - SD	GL - min [mm]	GL - max [mm]	GL - median [mm]	GL - SE	GL - CV
M. foina ♂	28	80.44	2.24	76.37	85.40	80.47	0.42	2.78
M. foina ♀	19	74.68	3.52	70.03	86.23	73.97	0.81	4.72
M. martes ♂	7	89.51	2.04	87.02	92.47	89.34	0.77	2.28
M. martes ♀	5	80.03	2.33	78.62	84.13	78.98	1.04	2.91
	Bd - n	**Bd - mean [mm]**	**Bd - SD**	**Bd - min [mm]**	**Bd - max [mm]**	**Bd - median [mm]**	**Bd - SE**	**Bd - CV**
M. foina ♂	28	10.33	0.50	9.33	11.83	10.25	0.09	4.84
M. foina ♀	19	9.51	0.61	8.38	11.31	9.45	0.14	6.39
M. martes ♂	7	10.50	0.49	9.85	11.13	10.53	0.19	4.71
M. martes ♀	5	9.14	0.48	8.38	9.62	9.28	0.21	5.23