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BIOSTATISTICAL INVESTIGATION OF LONG BONES AND METAPODIAL BONES OF *URSUS SPELAEUS* AND *URSUS DENINGERI*

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Abstract: This paper is on multivariate testing for species differentiation between *Ursus deningeri* and *Ursus spelaeus*. Significant results were achieved with twelve combinations of variables on nine postcranial elements in the discriminant analysis. These are attributed to a difference in locomotion habits, correlated to the differing diet of each species. These measurements were then used for the calculation of classification probabilities for the fossil finds of uncertain affiliation from the Einhornhöhle/Germany. A dominance of the geologically older *U. deningeri* is postulated here.

Key words: Ursids, Europe, Pleistocene, postcranial, statistics, species separation.

INTRODUCTION

Following a recent publication (Athen & Pfretzschner, 2005) data were evaluated from the Pleistocene *Ursus deningeri* and *Ursus spelaeus.* The data were gathered using 249 particular measurements on the skeletal elements humerus, ulna, radius, metacarpalia I-V, femur, tibia, fibula and metatarsalia I-V. For each of the 16 postcranial skeletal elements to be analysed between 8 and 25 variables and up to 56 instances per site are present. A new aspect of this study is that, along with the usual measurements, width and depth of the joint surfaces were also measured. The 2,890 specimens examined were from 12 sites in central Europe (fig. 1) and exclusively from adult individuals. The data was analysed using uni- and multivariate methods. The analyses have two goals. One is to discover species-defining characteristics. The other is to classify the finds from the Einhornhöhle (Unicorn Cave)/Germany as belonging to either species, *Ursus deningeri* or *Ursus spelaeus*.

Therefore, first all tests were applied to 2,295 specimens, excluding the finds from the Einhornhöhle. Next, the 595 specimens from Einhornhöhle were analysed. The statistical evaluation consisted of tests for normal distribution (Shapiro and Wilk's test) and variance (Levene test, ANOVA, Kruskal-Wallis test), of univariate (two sample tests for species distinction, *t*-test, Welch's *t*-test and the Mann-Whitney *U*-test) and multivariate main analyses (regression analysis, discriminant analysis, correlation analysis, factor analysis). The data from each species were examined in their entirety without subgroups (male/female).

RESULTS

The results of the univariate two sample tests determined significant differences between *Ursus deningeri* and *Ursus spelaeus* in 10.44% of the 249 analysed variables.

The multivariate discriminant analysis, requiring no normal distribution or homogeneous variances, could be applied to all data. The most important variables were the greatest length, proximal and distal breadth and thickness of the bones, also and especially of the joint facets. Using discriminant analysis of the logarithmized 249 variables twelve variable combinations could be identified which made a clear and certain division of the data into two groups possible, *Ursus deningeri* and *Ursus spelaeus.* In the data sets used here species separation was 100% accurate.

In a further examination process, those variables were eliminated which showed a strong correlation, as providing no significant information and being a possible source of inaccuracy. Factor analysis was used to pinpoint those combinations of factors indicating species separation. The combinations thus found were then examined again using discriminant analysis. The estimated

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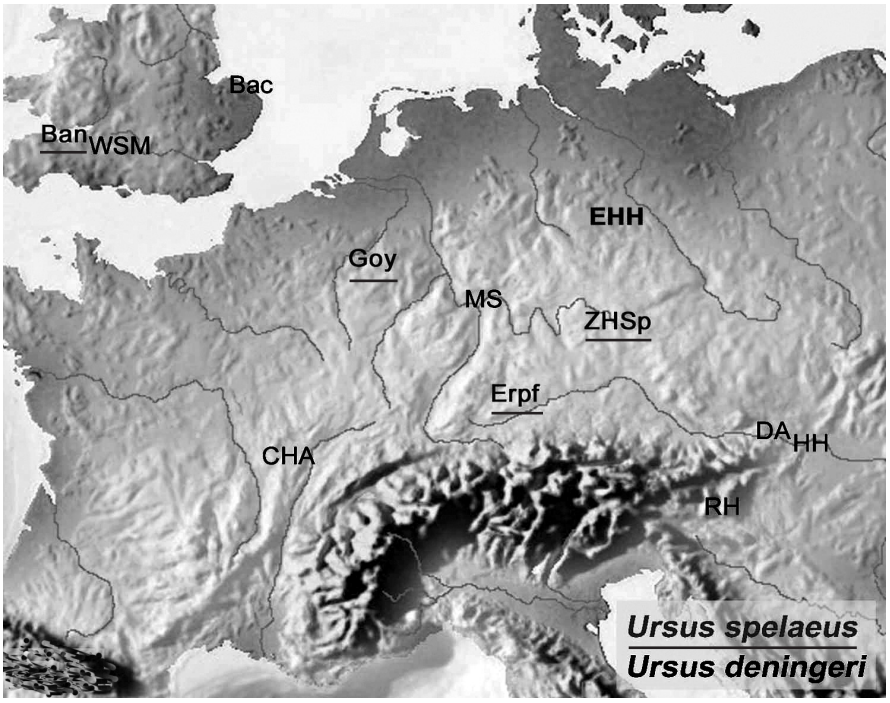

Figure 1. The location of the fossil sites in Europe. Finds of *Ursus deningeri* from Bacton/Nor-folk/United Kingdom (Bac), Château/Saône-et-Loire/France (CHA), Deutsch-Altenburg/Lower Austria (DA), Hundsheim/Lower Austria (HH), Mosbach-Sande/Wiesbaden/Germany (MS), Repolusthöhle/Styria/Austria (RH), Westbury-sub-Mendip/Somerset/United Kingdom (WSM). Selected fossil sites with finds of *Ursus spelaeus* from Banwell Bone Cave/Somerset/United Kingdom (Ban), Erpfingen/Swabian Alb/Germany (Erpf), Goyet/Condroz/Ardennes/Belgium (Goy), Zoolithenhöhle/Franconian Alb/Germany (ZHSp). The classification case is Einhornhöhle/Scharzfeld/Harz/Germany (EHH).

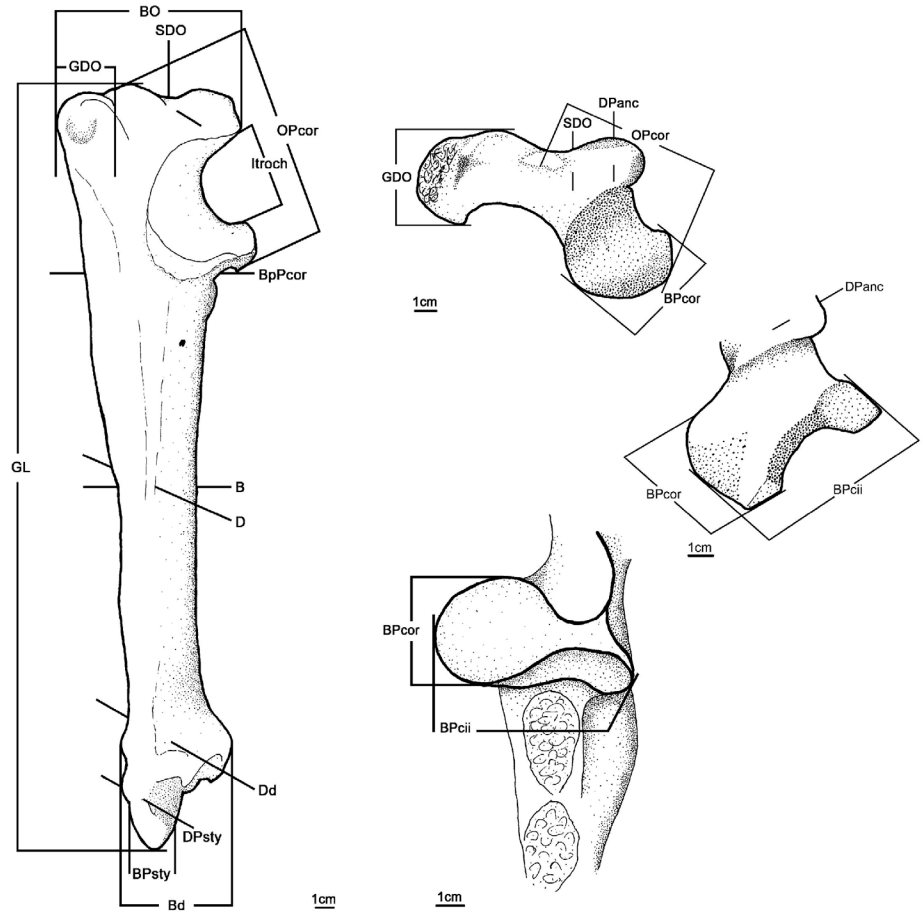

Figure 2. Ulna sinister, *Ursus spelaeus* specimen GPIT/MA/104 from Erpfingen, 16 measurements, GL (greatest length), B (breadth of diaphysis), D (thickness of diaphysis), BO (greatest breadth of the *Olecranon*), GDO (greatest thickness of the *Olecranon*), SDO (smallest thickness of the *Olecranon*), OPcor (from the most proximal part of the *Olecranon* to the *Processus coronoideus*), Itroch (distance of the outer margins of the *Incisura trochlearis* [*Cavitas sigmoides major*]), BpPcor (proximal breadth of the ulna at the level with *Processus coronoideus*), DPanc (greatest thickness of the *Processus anconaeus*), BPcor (greatest breadth of the *Processus coronoideus*), BPcii (greatest breadth of both *Processi coronarii*), Bd (greatest distal breadth), Dd (greatest thickness of the distal epiphysis), BPsty (breadth at the mean of the *Processus styloideus*), DPsty (thickness at the mean of the *Processus styloideus*). Most measurements were taken from Duerst (1926) and von den Driesch (1976).

values of the first three factors discovered through factor analysis were again subjected to discriminant analysis, in order to find variable combinations with factors leading to species separation. Based on these results, ten variable combinations on humerus, ulna, metacarpalia I, metacarpalia III, metacarpalia V, femur and metatarsalia V were worked out. Because of the small number of instances, the fibula was deemed less useful for this purpose than the other 15 skeletal elements. Five of these variable combinations were identical to the above discovered in the first discriminant analysis process. One will be taken as an example: ulna having the logarithmized variables of smallest depth of the *Olecranon* (ln_SDO), greatest thickness of the *Processus anconaeus* (ln_DPanc), greatest breadth of the *Olecranon* (ln_BO), from the most proximal part of the *Olecranon* to the *Processus coronoideus* (ln_OPcor), proximal breadth of the ulna at the level with *Processus coronoideus* (ln_BpPcor), greatest breadth of the *Processus coronoideus* (ln_BPcor), breadth at the mean of the *Processus styloideus* (ln_BPsty) (fig. 2, 3).

In both ursid species the ulna had its highest factor scores in the measurement OPcor, determined from the most proximal part of the *Olecranon* to the *Processus coronoideus*, and in its distal area. *Ursus deningeri* had a high factor score on the *Processi*, whereas in *Ursus spelaeus* there lay more emphasis on the greatest length of the bone and the smallest thickness of the *Olecranon* (SDO). The *t*-test, Welch's *t*-test and the *U*-test found significant differences between the two species in two variables with high factor scores on the proximal breadth of the ulna at the level with *Processus coronoideus* (BpPcor) and on the distance of the outer margins of the *Incisura trochlearis* (*Cavitas sigmoides major*, Itroch). Furthermore, opposite trends in both groups were found in the variable SDO: *Ursus spelaeus* showed a decrease, *Ursus deningeri* an increase in size during the time span from the geologically older finds (900,000 years) to the younger finds (30,000 years). The reason for this observation is not yet fully understood.

The results showed that all changing variables in the factor analysis were also good distinguishing features for species separation in the discriminant analysis. The results of the discriminant analysis and factor analysis match those of the *t*-test, Welch's *t*-test and the *U*-test. In both univariate and multivariate methods it is consistently the same set out of the 249 variables, which shows differences between the species - based on the mean values.

The above discovered significant variable combinations for reliable species separation were then used for

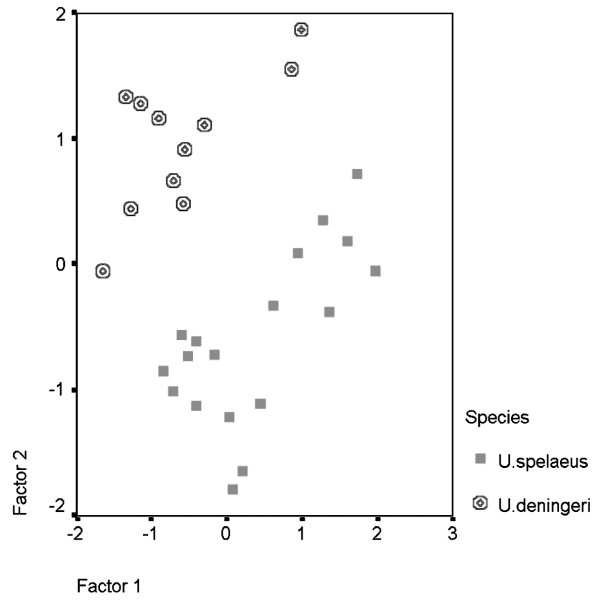

Figure 3. Plot of factor1 to factor2 in the factor analysis of the ulna (logarithmized data of GL, SDO, BO, OPcor, BpPcor, Itroch, Bpsty).

classification of the fossil finds from the Einhornhöhle (EHH, fig. 1). A lack of detailed stratigraphic information regarding the material from old excavations, which makes up the largest part of the 595 findings, has lead to some disagreement concerning species affiliation. So far it has not been possible to ascertain the absolute geological age of the fossils found. The discriminant analysis calculates probabilities for a correct classification of the material to either species. In these tests c. 60% of the processed postcranial material data from the Einhornhöhle could be identified as *Ursus deningeri* and c. 40% as *Ursus spelaeus.* Irrelevant for this classification was whether the finds originated from old or new excavations.

CONCLUSION

In this study species separation was possible on the above listed postcranial elements of 2,295 specimens of *Ursus deningeri* and *Ursus spelaeus*, unlike in some studies on dental material (Grandal d'Anglade & López Gonzalez, 2004). The results show that in the stylopodium, zygopodium and metapodium mostly the shaft width and thickness were significantly different. This is associated with increased roaming activity over large distances. Interestingly, species classification and factor extraction was possible especially with measurements of the proximal and distal joint surfaces. Within the scope of this investigation an observed lengthening of the zygopodium

in relation to the stylopodium also indicates an increased cursoriality. The mean values of the data sets analysed here also show that *Ursus spelaeus* was generally larger than *Ursus deningeri.* This is associated with increased herbivory and a genetic change, possibly due to migration especially of *Ursus deningeri*. The interpretation of the observations in this study is that the factor behind the differences, the cause, is a change in locomotion habits. The weight-supporting elements were strengthened, especially the anterior extremities, which would have been used increasingly to dig for roots and other food. It could be, that the ursids retreated south (southeast or southwest) and re-immigrated later in a more developed form. Climatic influence and subsequent changes in alimentation are also conceivable.

The majority of 595 fossil finds from the Einhornhöhle/Germany points towards a dominance of the *Ursus deningeri*-morphology group. There are different explanations for this observation. The fossil finds probably had accumulated over a long geological time span. Perhaps it was during the period of time, when *Ursus spelaeus* relieved *Ursus deningeri*. Possibly the specimens show the transition interpretation (von Koenigswald & Heinrich, 1999; Carls, Groiss & Rabeder, 1988) or a local variety (Rode, 1935). Apparently the Einhornhöhle was mainly populated by the geologically older *Ursus deningeri* whose remains during the course of sedimentation became mixed with those of the younger *Ursus spelaeus.*

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