Age re-assessment of the cave bear assemblage from Urșilor Cave, north-western Romania

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Abstract: The most common methods used for assessing the relative age of a cave bear bone assemblage are the $P^4/4$ index (morphodynamic index of the cave bear fourth premolar), the K-index, and the Index of Plumpness (both used for cave bear's 2nd metatarsal). Preliminary work on these indexes, for Urșilor Cave (NW Romania), has indicated one of the youngest European cave bear populations. As the number of extracted fossil bones from the palaeontological excavation increased recently, a re-assessment of the age of the cave bear assemblage is necessary. 206 cave bear fourth lower and upper premolars and 587 metapodials were analyzed. The $P^4/4$ morphodynamic index, the K-index and the Index of Plumpness were calculated for the local MIS 3 cave bear bone assemblage. The results of the three indices have lower values when compared with the previously obtained for the same site and respect the subsequent radiometric ages (ca. 47-39 ky BP). However, the results for $P^4/4$ morphodynamic index, K-index, and Index of Plumpness are of lesser relevance when used to assess the relative age of MIS 3 cave bear bone assemblages. All three methods require caution when applied and interpreted on short time intervals and on smaller geographic areas.

Keywords: *Ursus spelaeus*, biochronology, $P^4/4$ morphodynamic index, K-index, Urșilor Cave, Upper Pleistocene, Romanian Carpathians

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INTRODUCTION

The biochronology of fossil species is used for assessing the relative age of a bone assemblage. At the end of the 1980s and 1990s, Rabeder (1989, 1999) developed a biochronological index for cave bear assemblages, based on the evolutionary trend of the fourth premolars ($P^4/4$ index). This method can be applied when there is no radiometric age control for the fossils. The main issue with the morphodynamic index of the Marine Isotopic Stage 3 [MIS 3 (59-24 ky BP - Pettitt & White, 2012)] cave bear bone assemblages is that the method has standard errors that are too large when compared with the length of this period. Nonetheless, the obtained $P^4/4$ indices, plotted together with the results recorded for other sites, may provide a general time frame for the evolutionary level of a given cave bear population.

Another biochronological proxy often used in the cave bear research is the K-index. The K-index of the 2nd metatarsal is a suitable indicator of the evolutionary stage of a cave bear population, from the postcranial skeleton (Withalm, 2004). As older cave bear fauna

shows lower K-index values when compared with those from younger strata and this method shows a significant correlation with the radiometric scale, it represents a biochronological proxy for the age of cave bear bone assemblages (Withalm, 2001).

The Index of Plumpness (= *robustness*; Ip), applied on metapodials, is used as well for biochronological purposes. It has been shown that towards cave bears' extinction, Ip values increased as the metapodials became more robust (Withalm, 2001). As in the case of K-index, the most biochronologically relevant are the measurements on the 2nd metatarsals, since this bone seems to be less affected by the sexual dimorphism or by the ontogenetic variability like the other metapodials (Withalm, 2004).

For central and western European cave bear sites morphological studies based on dental features (Rabeder, 1995) that later were confirmed by molecular results (Hofreiter et al., 2004), proposed two distinct species within the European MIS 3 cave bear group: *U. spelaeus* and *U. ingressus* (Rabeder et al., 2004). The first species corresponds to the western clade of the group, while the second species

has a Central and Eastern European distribution. They separated between 414 ky BP and 173 ky BP according to molecular dating (Knapp et al., 2009; Baca et al., 2012). Two other additional MIS 3 cave bear subspecies were also identified in Alps: *Ursus s. ladinicus* and *Ursus s. eremus* (Rabeder et al., 2004a, 2006). From the Romanian Carpathians, the study on the phylogeny of the Oase Cave bears (Richards et al., 2008), based on an analysis of the morphology and mtDNA control region of 19 samples, found that the examined material shows clear affinity to populations from southern Germany, Austria, Croatia, and Slovakia (*U. ingressus* haplogroup). Other sites from the Romanian Carpathians (e.g., Urșilor, Cioclovina, Muierilor caves) with similar age of the cave bear thanatocoenosis and similar values of the $P^4/4$ index are susceptible of hosting the same fossil species (unpubl. material).

Urșilor (Bears) Cave is one of the most famous MIS 3 cave bear European sites and it includes a complete range of evidence belonging to this species: a full range of bioglyphs (nests, footprints, scratch marks, etc.) and several bone assemblages of different genesis throughout the cave system (*in situ* thanatocoenosis, reworked thanatocoenosis or mixed thanatocoenosis; Constantin et al., 2014; Robu, 2015, 2016b).

As the new excavation campaigns from the scientific reserve of the cave (lower level) brought out more cave bear bones and new results on direct dating (AMS ^{14}C dating) on fossil bones were recently obtained (Constantin et al., 2014), a re-assessment of the biochronology of the excavated bone assemblage was needed. Moreover, although Romania has a high density of MIS 3 bone deposits, only two previous cave bear sites were analyzed thoroughly: Oase (Quilès et al., 2006) and Cioclovina (Petrea, 2009) caves. Therefore, the results obtained at Urșilor Cave, along with the other two sites, on biochronology corroborated with the new radiocarbon data, will enhance understanding of MIS 3 cave bears from the Romanian Carpathians.

THE SITE

Urșilor Cave is situated the northwestern part of the Romanian Carpathians (Fig. 1A), its geological, geomorphological, and sedimentological background being discussed in detail in Constantin et al. (2014). The extracted fossil material was originally located at the lower level of the cave (= Scientific Reserve), in the Excavation Chamber and it derives from an *in situ* thanatocoenosis (Jurcsák et al., 1981; Robu et al., 2011; Robu, 2015, 2016a). The palaeontological excavation extends over an area of c. 9 m² and has a current depth of c. 2.3 m, without reaching the bedrock (Fig. 1B). Eight distinct sediment layers (labeled L I-VIII) were identified: L I-III, and L VIII are rich in cave bear remains, while the remaining layers are sterile. The bone beds extend across the whole section, while the lower sterile ones were found to be thicker along the A1-D1 transect and become thinner towards the D4 square, where they lie over a flowstone terrace (Fig. 1B) (Constantin et al., 2014; Robu, 2015).

The biochronological results obtained from Urșilor Cave were compared with the available data from the cave bear sites across Europe: Ukraine, Macedonia, Italy, Slovenia, Austria, France, Croatia, Slovakia, Germany, and Romania (Fig. 1A; Table 1).

MATERIALS AND METHODS

A morphodynamic investigation of the upper (P^4) and lower fourth premolars (p^4) was carried out, applying the method developed by Rabeder (1989, 1999) and Rabeder & Tsoukala (1990), on 206 specimens ($N = 206$), ranging from juveniles to adults, from the palaeontological excavation within Urșilor Cave (103 specimens of P^4 and 103 specimens of p^4). This method is based on the evolutionary trend in the occlusal plan for the fourth premolars and has been discussed in Robu et al. (2011).

Almost 590 cave bear metapodials ($N = 587$) from the palaeontological excavation were investigated, out of which 338 were metacarpals and 249 were metatarsals. The osteometric measurements were performed following the methodology proposed by Tsoukala and Grandal D'Anglade (2002), using a 150 mm electronic caliper (± 0.01 mm accuracy). As in Robu et al. (2011), K-index was erroneously used (focusing on the 4th metatarsal), now the use of K-index (equations 1 and 2; Fig. 2) has emphasized the evolutionary relevance of the 2nd metatarsal bone ($N = 44$); the method proposed by Gužvica & Radanović-Gužvica (2000) and the Index of Plumpness (equations 3 and 4) were previously presented in detail in Robu et al. (2011). The measurements and the equations used for the calculation of both indices are shown in Fig. 2. For the equation [1], DT_{prox} represents the proximal breadth, DAP_{prox} , the proximal height, and L is the greatest length (= *maximum length*). The standardization of the obtained K-index [2] was made with the MIS 3 cave bear population from Gamssulzen Cave (K-index = 5.63; Withalm, 2004). The Index of Plumpness was calculated according to Withalm (2001). For the equation [3], DT_{dist} is the distal breadth and L , the greatest length. The standardization was made with the MIS 3 cave bear population from Gamssulzen Cave (Withalm, 2001) and the equation used was [4].

The values obtained from Urșilor Cave for the $P^4/4$ index, K-index, and Index of Plumpness were correlated with the radiometric scale and were plotted with other similar MIS 3 European cave bear sites. Only the AMS ^{14}C data of the European MIS 3 cave bears were taken into consideration for this study.

In order to test the validity of the K-index, several correlations between the axes involved in its calculation were carried out. This test was performed on the 2nd metatarsus from the palaeontological excavation.

RESULTS AND DISCUSSION

$P^4/4$ morphodynamic index

The dominant p^4 morphotypes are C1 (protoconid, paraconid and metaconid), C2 (C1 + hypoconid), D1 (protoconid, paraconid, metaconid and two small

Fig. 1. A) Location of several MIS 3 European cave bear sites; numbers assigned to sites correspond to Table 1; B) Location and topography of Urșilor Cave with position of the palaeontological excavation.

accessory cusps) and D2 (D1 + hypoconid). C1, the most common morphotype of the lower fourth cave bear premolars from this palaeontological excavation, represents 26.21% of the total number of analyzed specimens. The D1 and D2 morphotypes have the same representation (14.56%), while C2 has a value of 12.62% (Fig. 3; Table 2).

The dominant P4 morphotypes are D (protocone, metacone, hypocone, metalophe + small accessory cusps) and E (D + a better emphasized metalophulus and hypolophulus). The D morphotype accounts for almost 62% of the total, while the E morphotype represents 16.50% (Fig. 3; Table 2).

The p4 index calculated for the cave bears from this palaeontological excavation is 184.95, while

the value obtained for P4 is 204.85. After the standardization using the data from Gamssulzen Cave, the standardized $P^4/4$ index for Urșilor Cave is 65.04, which places roughly this cave bear population within MIS 3 period and indicate an affiliation to the *Ursus ingressus* group. Moreover, these results on dental features of the fourth premolar suggest that Urșilor cave bear population is situated at the middle, between the most (e.g., Nixloch, Potočka zijalka) and less developed (e.g., Nerubajskoe) occlusal surfaces of *Ursus ingressus* populations. Nonetheless, the correlation between the $P^4/4$ index and the radiometric scale ($R^2 = 0.25$) of the plotted MIS 3 cave bear sites from Europe indicates a weak interdependence between the two parameters (Fig. 4).

Table 1. Several MIS 3 European cave bear sites and their biochronological indices. *Note:* the assigned numbers (#) to the analyzed sites correspond to Figs. 1, 4, and 5.

#	Site	Country	Standardized $P^4/4$ index	Standardized K-index (2 nd metatarsal)	Standardized Ip (2 nd metatarsal)	Radiometric dating (ky cal BP)	Species	Source
1	Nixloch	AU	109.2	–	–	28.89	<i>Ursus ingressus</i>	Döppes & Rabeder, 1997; Rabeder, 1999; Rabeder et al., 2004b; Pacher & Stuart, 2009
2	Gamssulzen	AU	100	100.00	100.00	40.48	<i>Ursus ingressus</i>	Rabeder, 1995; Döppes & Rabeder, 1997; Rabeder et al., 2004b; Pacher & Stuart, 2009
3	Herdengel 200-330	AU	58.95	95.56	96.51	40	<i>Ursus ingressus</i>	Döppes & Rabeder, 1997; Rabeder, 1999; Rabeder et al., 2004b; Pacher & Stuart, 2009
4	Urşilor	RO	65.04	97.87	92.11	42	<i>Ursus ingressus?</i>	Robu et al., 2011; Constantin et al., 2014; Robu, 2015; 2016a,b.
5	Oase Cave	RO	72.5	–	–	48	<i>Ursus ingressus</i>	Quilès et al., 2006; Richards et al., 2008
6	Cioclovina Uscata	RO	79.3	–	–	40	<i>Ursus ingressus?</i>	Petrea, 2009
7	Ilinka	UK	50	100.18	93.87	41	<i>Ursus ingressus</i>	Rabeder et al., 2008; Nagel et al., 2005
8	Križna jama	SLO	86.19	109.59	100.72	39.62	<i>Ursus ingressus</i>	Rabeder & Nagel, 2001; Pohar et al., 2002; Rabeder et al., 2008
9	Nerubajskoe	UK	30	86.50	95.16	52.45	<i>Ursus ingressus</i>	Nagel et al., 2005
10	Potočka zijalka	SLO	104	103.37	102.04	30.4	<i>Ursus ingressus</i>	Rabeder et al., 2004b; Pacher et al., 2004; Pacher & Stuart, 2009
11	Vindija	CR	63.75	110.83	100.25	39.4	<i>Ursus ingressus</i>	Wild et al., 2001; Rabeder et al., 2004b; Withalm, 2005
12	Divje Babe	SLO	87	–	–	47.7	<i>Ursus ingressus</i>	Debeljak, 2002; Wild et al., 2001; Rabeder et al., 2008; Toškan, 2006
13	Loutra Arideas	MA	75.66	93.78	97.01	38	<i>Ursus ingressus</i>	Rabeder et al., 2006
14	Bucco dell'Orso	IT	–	129.66	103.58	–	<i>Ursus ingressus</i>	Santi et al., 2011; Santi & Rossi, 2014
15	Medvedia	SL	79.09	–	–	47.1	<i>Ursus ingressus</i>	Sabol et al., 2008
16	Salzofen	AU	57.99	–	–	49.2	<i>Ursus eremus</i>	Döppes & Rabeder, 1997; Rabeder, 1999; Rabeder et al., 2008; Döppes et al., 2011
17	Ramesch 3	AU	52.85	–	–	53.2	<i>Ursus eremus</i>	Draxler et al., 1986; Döppes & Rabeder, 1997; Rabeder, 1999; Pacher, 2003; Rabeder et al., 2004b; Döppes et al., 2011
18	Brettsteinbären	AU	53	97.87	100.66	51.3	<i>Ursus ladinicus</i> + <i>Ursus eremus</i>	Döppes & Rabeder, 1997; Rabeder et al., 2008; Pacher & Stuart, 2009
19	Conturines	IT	63.97	88.10	97.86	44.2	<i>Ursus ladinicus</i>	Rabeder, 1991; Rabeder, 1999; Rabeder et al., 2004b; Hofreiter et al., 2004
20	Ajdovska jama	SLO	46.78	100.00	94.94	50	<i>Ursus ladinicus</i>	Rabeder, 2011; Rabeder et al., 2011; Pacher, 2011; Withalm, 2011
21	Zoolitenhöhle	GE	42	100.89	92.93	34.7	<i>Ursus s. spelaeus</i>	Rabeder et al., 2004b; Hofreiter et al., 2004
22	Fontana Marella	IT	57.8	–	–	26	<i>Ursus ingressus?</i>	Toskan & Bona, 2012; Santi & Rossi, 2014
23	Caverna Generosa	IT	56.82	–	–	47.14	<i>Ursus ingressus?</i>	Bona, 2004; Pacher & Stuart, 2009; Santi & Rossi, 2014
24	Basura	IT	95.1	–	–	27.5	<i>Ursus s. spelaeus?</i>	Quilès et al., 2006; Petrea, 2009
25	Tournal	FR	73.4	–	–	35	<i>Ursus s. spelaeus?</i>	Santi & Rossi, 2014
26	Hortus	FR	80.9	–	–	40	<i>Ursus s. spelaeus?</i>	Petrea, 2009; Santi & Rossi, 2014
27	Grotte Blanche	FR	79.8	–	–	40	<i>Ursus s. spelaeus?</i>	Petrea, 2009
28	Badalucco	IT	72.4	–	–	50	<i>Ursus s. spelaeus?</i>	Petrea, 2009

Anterior view

Distal view

$$K = \frac{Dtprox \times DAPprox}{L} \quad [1]$$

$$K_{standUrşilor} = \frac{K_{index Urşilor}}{K_{index Gamssulzen}} \times 100\% \quad [2]$$

$$Ip = \frac{Dtdist}{L} \times 100\% \quad [3]$$

$$Ip_{standUrşilor} = \frac{Ip Urşilor}{Ip Gamssulzen} \times 100\% \quad [4]$$

Fig. 2. Osteometric measurements and the equations used for the calculation of K-index and Index of Plumpness.

Table 2. The cave bear upper (P4) and lower (p4) morphotypes from the palaeontological excavation.

Upper P4				
Morphotype	Amount	Factor	Product	Frequency (%)
B	3	1	3	2.91
C	3	2	6	2.91
A/D	13	1	13	12.62
D	64	2	128	62.14
E	17	3	51	16.50
D/F	1	3	2	0.97
F	2	4	8	1.94
TOTAL	103		211	100
Lower p4				
Morphotype	Amount	Factor	Product	Frequency (%)
B1	6	0.5	3	5.82
B2	2	2	4	1.94
C1	27	1	27	26.21
C2	13	2	26	12.63
C3	8	3	24	7.76
D1	15	1.5	22.5	14.57
D2	15	2.5	37.5	14.57
D3	7	3.5	24.5	6.79
E1	9	2	18	8.73
E3	1	4	4	0.98
TOTAL	103		190.5	100

Fig. 3. Main P₄⁴ morphotypes from Urşilor Cave.

Fig. 4. Radiometric ages vs. $P^4/4$ standardized index for several European cave bear sites. Note: numbers assigned to sites correspond to Table 1.

For the pooled cave bear fourth premolars from Urşilor, a biochronological estimate of 60–40 ky BP was obtained based on the assumed error of the morphodynamic method and taking into account the cave bear extinction date, situated around 27.8 cal ky BP (Pacher & Stuart, 2009).

At the European continental scale, spanning a time period of almost 140 ky BP (Rabeder & Tsoukala, 1990; Quilès et al., 2006), the dental morphotype indices are well correlated with the radiometric scale, and therefore, the $P^4/4$ morphodynamic index has proved to be a reliable biochronological tool (e.g., Rabeder, 1999; Quilès, 2004). Nevertheless, in the case of the plotted European MIS 3 cave bear populations, the relevance of the calculated index loses its validity: the correlation between the $P^4/4$ index and the radiometric scale of is weak ($R^2 = 0.25$). This could be explained by 1) the amount of new radiocarbon data obtained through AMS using ultrafiltration, which have given significantly older dates on the same fossil material (Higham et al., 2006a, b; Jacobi et al., 2006; Mellars, 2006; Pacher & Stuart, 2009) and 2) the contradiction between the obtained $P^4/4$ index and the radiocarbon data [e.g., the values of the morphodynamic index obtained for Oase Cave (72.5; see Table 1) indicated a more advanced evolutionary stage for the cave bears than at Urşilor Cave, while the obtained radiometric ages clearly show that the latter site was younger than Oase Cave].

Therefore, one of the main limitations of the $P^4/4$ morphodynamic method (when attempting to estimate the age of a MIS 3 cave bear bone population), is that the long-term adaptive features in addition to the local environmental conditions affect the fourth premolar's "plasticity". In other words, although the radiometric results may point to a younger cave bear population at one site than at another, the former may retain less complex features in the dental configuration than the latter. In this situation, the main constraint cannot be the general trend of the evolution, but the local environmental factors or other constraints (e.g., the geographic and reproductive isolation, the variability of $P^4/4$'s occlusal surface in a given place and time, dietary habits, etc.) that could have shaped the $P^4/4$,

morphology differently for various populations. The second main limitation is that within MIS 3, the $P^4/4$ morphodynamic index has a very low resolution (the errors of the method are far too large for this period). As such, it is hard to assess the evolutionary stage of a cave bear population, especially when $P^4/4$ ' "molarisation" was not necessarily an evolutionary trend as they approached extinction but seems rather related to the variability of this species during MIS 3. Consequently, based on our new biochronological results obtained from Urşilor Cave we consider that the use of the $P^4/4$ morphodynamic estimation is a less reliable tool when trying to assess and to compare the $P^4/4$ dental features between cave bear populations from similar time periods (e.g., 45–40 ky BP).

Nonetheless, the method can be applied with caution when no radiometric ages are available for the fossil remains and when the evolutionary stage of the cave bear population has to be broadly assessed. Moreover, based on the biochronological estimates obtained from the quantification of the $P^4/4$ occlusal surface of cave bears from the European sites it appears that the $P^4/4$ index may provide reliable information when conducting studies on a regional scale and at larger time.

K-index and Index of Plumpness

The K-index value obtained for the 2nd metatarsal of the cave bears from the palaeontological excavation is 5.51 (Table 3). After standardization using the data from Gamssulzen Cave, a K-index value of 97.86 was recorded for Urşilor Cave.

Figure 5A shows the distribution of the best studied European cave bear sites (e.g., Rabeder, 1999, 2004; Gužvica & Radanović-Gužvica, 2000; Withalm, 2004, 2011) taking into consideration two variables: the K-index and the radiocarbon data. As the occlusal surface of the fourth premolar indicates, the values obtained for the cave bears from the palaeontological excavation point to a cave bear population situated at an earlier evolutionary stage when compared to the other western and central European *Ursus ingressus* cave bear populations. However, the result of the correlation ($R^2 = 0.22$), between the radiometric scale and the K-index from the analyzed sites, suggests that K-index should be regarded with caution as a biochronological proxy.

The Index of Plumpness calculated for the 2nd metatarsal of the cave bear population from Urşilor Cave is 29.31 (Table 3). Figure 5B shows the available standardized indices of Plumpness plotted against the radiometric scale from the European cave bear sites. Among the analyzed cave bear sites, Urşilor population has the lowest value of the Index of Plumpness, although the obtained radiometric data place this population later than other sites with higher values of robusticity. The correlation between radiocarbon data and Ip is weak ($R^2 = 0.03$) and apparently, as in the case of the K-index, the assumed biochronological relevance of this index is questionable.

It is known that during MIS 3 different cave bear species/subspecies coexisted (even in the same site; e.g., Gamssulzen and Ramesch caves; Bocherens et al., 2011), sometimes showing different body

Fig. 5. A) Radiometric ages vs. standardized K-index index for several European cave bear sites; B) Radiometric ages vs. standardized Index of Plumpness for several European cave bear sites. *Note:* numbers assigned to sites correspond to Table 1.

Table 3. Measurements of the cave bear metapodials from Urșilor Cave (according to Tsoukala & Grandal D'Anglade, 2002). *Note:* Mc = metacarpals; Mt = metatarsals; L = greatest length; DT prox. = the proximal breadth; DAP prox. = the proximal height; DT dia.min. = minimum breadth of diaphysis; DAP dia. = diaphysis' height; DT dist. = the distal breadth; DAP dist. = the distal height; DT art.dist. = the distal articulation breadth.

Elements	Mc 1	Mc 2	Mc 3	Mc 4	Mc 5	Mt 1	Mt 2	Mt 3	Mt 4	Mt 5
L	63.51	75.87	80.94	83.22	83.16	55.52	69.23	78.36	85.77	90.05
DT prox.	23.53	18.51	20.07	21.74	27.54	21.92	15.87	20.05	20.01	28.14
DAP prox.	20.73	25.3	29.01	30.49	30.54	23.48	24.03	29.12	29.57	29.85
DT dia.min.	13	17.01	16.5	18.25	18.3	11.1	13.56	15.09	15.27	13.83
DAP dia.	11.2	13.12	13.4	15.46	14.7	12.2	10.35	11.48	13.41	14.87
DT dist.	18.26	24.04	24.35	26.04	27.01	17.14	20.3	21.23	22.55	24.4
DAP dist.	17.3	19.63	20.49	21.17	20.16	15.66	16.24	16.87	17.7	17.74
DT art.dist.	12.27	16.36	15.91	15.91	16.72	10.72	12.71	12.78	14.95	14.82
Ip	28.75	31.68	30.08	31.29	32.47	30.87	29.31	27.09	26.28	27.1
K	7.68	6.17	7.19	7.37	10.11	9.27	5.51	7.45	6.9	9.32

sizes and biometric peculiarities. Therefore, several correlations were tested for a better understanding of the K-index and for its biochronological relevance. The working assumption was that if there is a strong interdependence among all the parameters - the greatest length, the DAP prox (antero-posterior diameter of the proximal epiphysis) and the DT prox (transverse diameter of the proximal epiphysis) - then the equation proposed by Gužvica & Radanović-Gužvica (2000) has no biochronological meaning (strong correlations among all the axes, indicate that the largest bears (as size of the skeleton) will produce only high values for the K-index, but not a palaeoevolutionary proxy). The results indicated that:

(i) the correlation between the DAP prox and the K-index (Fig. 6A) of the 2nd metatarsal of the cave bears from the palaeontological excavation at Urșilor Cave is significant ($R^2 = 0.70$);

(ii) the correlation between the K-index and the greatest length (or maximum length) of the second metatarsal (Fig. 6B) is non-significant ($R^2 = 0.37$);

(iii) figure 7A shows a strong correlation ($R^2 = 0.90$) between the K-index and the (DT prox);

(iv) the correlation between the DAP prox and the DT prox (Fig. 7B) is moderate ($R^2 = 0.59$) and indicates that the axes are not interdependent;

(v) figure 8A shows a significant correlation between the maximum length and the antero-posterior diameter ($R^2 = 0.76$) of the cave bear 2nd metatarsal;

(vi) the maximum length and the transverse diameter of the proximal epiphysis (Fig. 8B) shows no interdependence between the axes ($R^2 = 0.46$).

K-index appears to reflect the robusticity of the proximal end of the metatarsals. As Withalm (2004) mentioned, K-index values obtained for cave bears increased as they approached extinction [i.e., older bears (from deeper stratigraphic layers) show lower values than those from younger strata]. These correlations have shown that the maximum length of the 2nd metatarsal exhibits a pattern similar to that of the antero-posterior diameter, while the transverse diameter does not show a clear interdependence with either the maximum length or DAP. For the 2nd metatarsal of the cave bears from the palaeontological excavation, DAP and maximum length seem to be interrelated, while DT behaves as an independent parameter.

Nonetheless, for a better assessment of the age estimation of a cave bear population, the obtained K-index has to be correlated with the $P^4/4$ index and with the Index of Plumpness. Thus, if the $P^4/4$ morphodynamic index, K-index and Index of Plumpness are correlated with the radiometric scale (Withalm, 2004), the obtained results might be of biochronological relevance. However, the main concern, as in the case of the $P^4/4$ index (for both K-index and the Ip) is the resolution of the methods – errors far too large for a

Fig. 6. A) K-index vs. DAP prox for the 2nd cave bears metatarsal; B) K-index vs. GI for the 2nd metatarsal of the cave bears from the palaeontological excavation from Urşilor Cave.

Fig. 7. A) K-index vs. DT prox for the 2nd metatarsal; B) DAP vs. DT for the 2nd metatarsal of the cave bears from Urşilor Cave.

Fig. 8. A) DAP prox vs. greatest length for the 2nd metatarsal; B) DT prox vs. greatest length for the 2nd metatarsal of the cave bears from Urşilor Cave.

precise evaluation of the age of the MIS 3 cave bear populations.

CONCLUSIONS

Based on the morphodynamic dataset ($P^4/4$) and indices for 2nd metatarsus (K and Ip indices), Urşilor Cave bear population is allocated to an earlier evolutionary stage than previously assumed by Robu et al. (2011). Most likely this cave bear population belongs to a more ancient branch – with less evolved dental and metapodial features – of *Ursus ingressus* population (eastern clade) when compared with similar MIS 3 populations from the alpine region (western clade). The earlier evolutionary stage might indicate an older period, a fact also supported by the radiometric data.

All three methods, $P^4/4$ morphodynamic index, K-index, and Index of Plumpness, often used for the cave bear evolutionary stage assessment, are biochronologically relevant when corroborated and applied at a regional scale and to large time intervals. For the MIS 3 cave bear populations, the use of these three indices for biochronological purposes, without proper radiometric dating, may be unreliable.

Over the last 30 years, the radiometric ages were obtained using different procedures (e.g., conventional ^{14}C , AMS ^{14}C with ultrafiltration), thus a full reassessment of both the biochronological ($P^4/4$, K, and Ip indices) and the radiometric data – for the most relevant cave bear sites – is needed. Until then, all correlations of the biochronological indices vs. the radiometric scale should be interpreted with caution.

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