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The lower first molar (m₁) of *Ursus* gr. *spelaeus* from Valsolda (Lombardy, Italy): Morphometry and morphodynamic analyses and considerations on the evolutionary step.

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Ursus gr. *spelaeus* | erster unterer Backenzahn | Evolution | Valsolda | Norditalien

Abstract: Valsolda is located in Lombardy (N. Italy) near the border with Switzerland, and from the Buco della Noga cave bear remains have been gathered. In this study the first lower molar (m₁) is morphometrically and morphodynamically examined. With these data it is difficult to indicate the taxon, and therefore prudentially this population is inserted in a generic *Ursus* gr. *spelaeus*, and the presence of *U. ingressus* is not proven. In the PCA analysis the position of some of the Italian caves (Conturines, Valsolda, Grotta del Bandito, Mount Fenera) is very clear and reflect the morphometrical features of the bears belonging to two or more different taxa.

Kurzfassung: Valsolda liegt in der Lombardei (Norditalien) nahe der Grenze zur Schweiz, und aus der Höhle Buco della Noga wurden Bärenreste gesammelt. In dieser Studie wird der erste untere Backenzahn (m₁) morphometrisch und morphodynamisch untersucht. Mit diesen Daten ist es schwierig, das Taxon anzugeben, und daher wird diese Population vorsichtshalber in einen generischen *Ursus* gr. *spelaeus* eingefügt, und das Vorhandensein von *U. ingressus* konnte nicht nachgewiesen. In der PCA-Analyse ist die Position einiger italienischer Höhlen (Conturines, Valsolda, Grotta del Bandito, Mount Fenera) sehr eindeutig und spiegelt die morphometrischen Merkmale der Bären wider, die zu zwei oder mehr verschiedenen Taxa gehören.

Introduction

Cave bears were wide-spread in Northern Italy, and have been found in every region except for Valle d'Aosta; caves that possibly contained remains from different taxa are particularly important. This could be the case for the *Ursus* gr. *spelaeus* population that used to live in Valsolda (Como Province, Lombardy) close to the border with Switzerland (**Fig. 1**). Recently Frischauf et al. (2017) described remains found in Steigelfadbalm (Lucerne, Switzerland) as belonging to *Ursus ingressus*, so there is a possibility that these bears made their way into this valley.

Recently Santi & Rossi (2020) studied the teeth of the population from the Buco della Noga cave in Valsolda except for the first inferior molars (m₁) which will be the subject of this study; this way we will have an almost complete idea of their morphometric and morphodynamic qualities in order to make a more precise hypothesis of the evolutionary step reached by cave bears in Northern Italy.

Geographical setting of the Buco della Noga (Valsolda)

During the 1883 excavation in Valsolda, many cave bear remains were collected by Prof. Castelfranco and are currently kept in the Museo Civico di Storia Naturale in Milan and in the Museo Cantonale di Storia Naturale in Lugano. Valsolda (Como Province, Lombardy) is located close to the border with Switzerland; its most important cave is Buco della Noga, known also as »Grotta dell'Orso« and, in the local idiom, as »Bus de la Noga« (Dal Negro, 2004, **Fig. 1**). The entrance is at 1310 m above sea level, the cave is dug in the main dolomite (Carnian-Norian, 215-204 Ma) and it develops for about 50 m of length from the entrance and reaches 38 m of depth, it is 3-4 m tall and 4m wide. The bottom is filled with abundant debris.
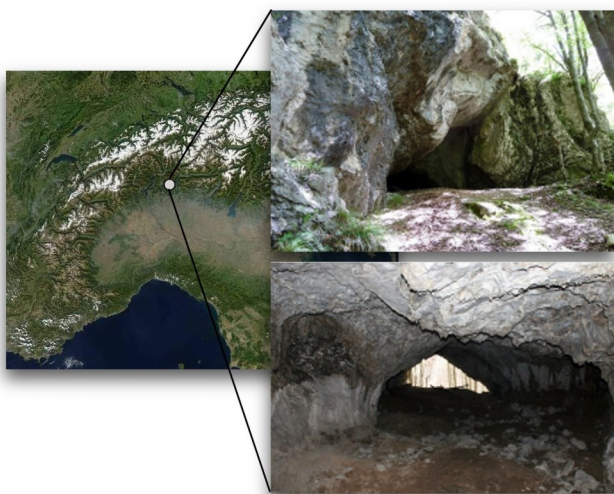

Fig. 1: Geographical position of the Valsolda and some details of the Buco della Noga (from Santi & Rossi, 2020). | **Abb. 1**: Geografische Lage des Valsolda und einige Details des Buco della Noga (aus Santi & Rossi, 2020).

Materials and methods

The first lower molars (m₁, n. 26) from the Museo Civico di Storia Naturale of Milan have been studied through morphometric and morphodynamic analyses; in the first case by following the parameters set by Grandal d'Anglade & López Gonzalez (2004) and Baryshnikov & Puzachenko (2020), in the second case following the methods of Rabeder (1999). The Past 3.2 software (Hammer et al., 2001) has been used to offer a first approach to basic statistics. **Fig. 2** shows not only the main statistics but also compares the sizes of m₁s from Valsolda with those of other Italian caves and those of populations from the Caucasus and the Urals (*U. praekudarensis*, *U. praekudarensis/kudarensis* and *U. kudarensis*). The different lines show similar if not the same trend both for Italian and Russian populations taken as a comparison, showing that there is no size variation in this type of tooth between these populations.

Discussion

Morphometry

Point distribution referring to the relationship between length and width of the m₁s from Valsolda (**Fig. 3A**) is not different from those of other Italian caves taken as comparison; at the same time, looking at **Fig. 3B-D**, it appears that there are not substantial differences between the size of the m₁ when comparing it with those of *U. ingressus*, *U. spelaeus eremus* and *U. spelaeus ladinicus*; because of that it is difficult to identify the specific taxon based only on these parameters. Very interesting is the diagram in **Fig. 4**, which shows the distribution of cave bear populations from Valsolda, Mt. Fenera (Borgosesia, Piedmont) and from European caves. Valsolda's population sits far away from the position taken by the Gamssulzen cave (*U. ingressus*); not only, but populations respectively from Conturines (*U. s. ladinicus*), Ramesch (*U. s. eremus*), Repolust (*U. deningeroides*) and Westbury (*U. deningeri*) are placed together and far from Gamssulzen cave as well. This might suggest that, at least by looking at these parameters, a stable presence of *U. ingressus* in Valsolda can be excluded. It could have been possible to suppose that *U. ingressus* had been present in Valsolda since Frischauf et al. (2017) proved that he used to live in Steigelfadbalm (Lucerne). In this diagram this cave (ST) sits close to the Gamssulzen cave; because of this, we can confirm that *U. ingressus* individuals didn't cross the Italian border to reach Buco della Noga.

A first approach to multivariate analysis is summarized in the diagrams of **Fig. 5**, where we show the correspondence analyses (CA), one based on the indices of Grandal d'Anglade & López Gonzalez (2004) (PadCI, TadCI, TrdCI), the other based on the main components (PCA) by using length, width and the indices shown above (PadCI, TadCI, TrdCI, **Fig. 5B**). With these indices, the positions of Valsolda and of the other Italian caves we have used as a comparison fall within of a very restricted area made by the overlapping points: we can deduce a strong relationship between these bear populations exists (**Fig 5A**). In the second diagram (**Fig. 5B**) we can see two well-defined fields: one made
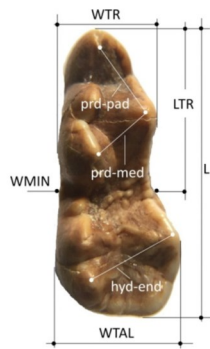
$IW = (0.5.(WTR+WTAL))/L \cdot 100$

$ILTRL = (LTR/L) \cdot 100$

$ILTA = (1-LTR/L) \cdot 100$

$IWTR\text{-}TAL = (WTR/WTAL) \cdot 100$

$IWTR = (WTR/L) \cdot 100$

$IWTAL = (WTAL/L) \cdot 100$

$IS = ((WTR.LTR) + ((L-LTR) \cdot WTAL))/100$

$PadCI = ((pr\text{-}pa)/LTR) \cdot 100$

$TrdCI = ((pr\text{-}me)/WTR) \cdot 100$

$TadCI = ((hy\text{-}en)/WTAL) \cdot 100$

Parameters	L	LTR	WTR	WTAL	prd-pad	pr-med
Mean	29.61	17.59	11.23	13.48	9.58	7.38
St. dev.	1.85	1.38	0.85	1.10	1.29	0.88
Min.	26.43	14.78	9.63	11.37	6.1	4.96
Max.	33.05	20.07	12.76	15.83	11.17	8.99
St. err.	0.50	0.37	0.21	0.25	0.32	0.21
n. specim.	14	14	16	20	16	18

Parameters	hyd-end	WIN	IW	ILTRL	ILTA	IWTR_TAL
Mean	9.65	10.43	41.71	59.42	40.58	82.14
St. dev.	1.25	1.26	1.74	3.22	3.22	3.01
Min.	6.11	8.26	38.62	53.35	36.15	77.56
Max.	12.2	12.49	44.46	63.86	46.65	86.77
St. err.	0.28	0.28	0.50	0.93	0.93	0.86
n. specim.	20	20	12	12	12	12

Parameters	IWTR	IWTAL	IS	PadCI	TrdCI	TadCI
Mean	37.71	45.95	3.57	54.44	65.75	71.64
St. dev.	1.58	2.13	0.44	5.54	7.75	7.72
Min.	35.6	41.65	2.79	41.27	46.53	47.59
Max.	40.33	48.58	4.1	63.3	80.17	84.82
St. err.	0.46	0.62	0.13	1.48	2.00	1.73
n. specim.	12	12	12	14	15	20

Parameters	PK	PK/K	K	VALSOLDA
L	28.5±0.14	28.2±0.21	27.6±0.21	29.61±0.5
LTR	18.1±0.12	17.7±0.16	17.4±0.17	17.59±0.37
WTR	10.9±0.07	11.1±0.13	10.9±0.10	11.23±0.21
WTAL	13.5±0.07	13.9±0.13	13.8±0.11	13.48±0.24
WMIN	10.8±0.07	11.2±0.13	11.1±0.11	10.51±0.28
IW	42.8±0.18	44.3±0.22	44.7±0.26	41.71±0.5
IS	3.4±0.04	3.4±0.06	3.3±0.05	3.57±0.13
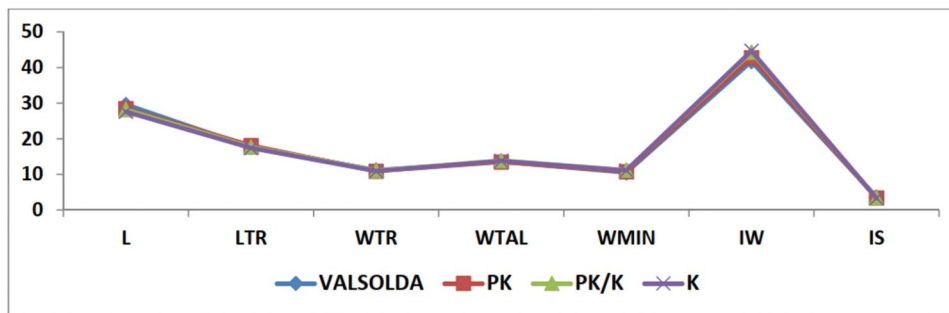
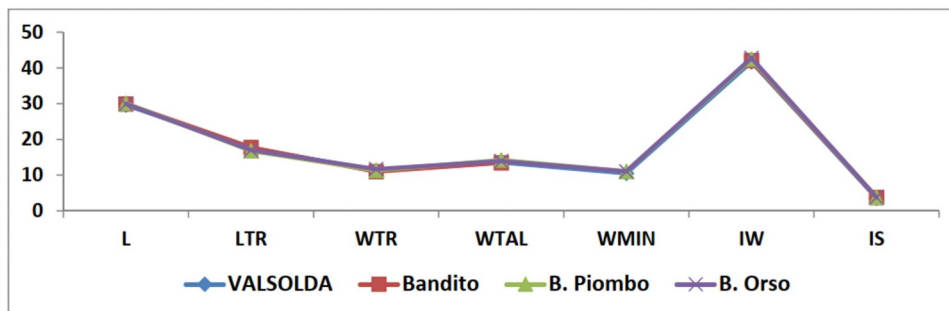| Parameters	Gr. Bandito	B. Piombo	B. Orso	VALSOLDA
L	29.90±0.24	30.11±0.34	29.9±0.64	29.61±0.5
LTR	17.74±0.23	16.79±0.20	17.00±0.52	17.59±0.37
WTR	10,98±0.13	11.32±0.14	11.68±0.33	11.23±0.21
WTAL	13.46±0.21	14.22±0.15	13.94±0.46	13.48±0.25
WMIN		11.04±0.16	11.14±0.31	10.51±0.28
IW	42.06±0.35	42.46±0.39	42.79±0.61	41.71±0.5
IS	3.74±0.071	3.8±0.08	3.78±0.18	3.57±0.13

Fig. 2: Main statistical data of the parameters referred to first lower molar of the bears from Valsolda and correlation lines of the main parameters in cave bears from Caucasus, Urals, the Italian caves and Valsolda. | **Abb. 2**: Statistische Hauptdaten der Parameter des ersten unteren Molaren der Bären aus Valsolda und Korrelationslinien der Hauptparameter bei Höhlenbären aus dem Kaukasus, dem Ural, den italienischen Höhlen und Valsolda.
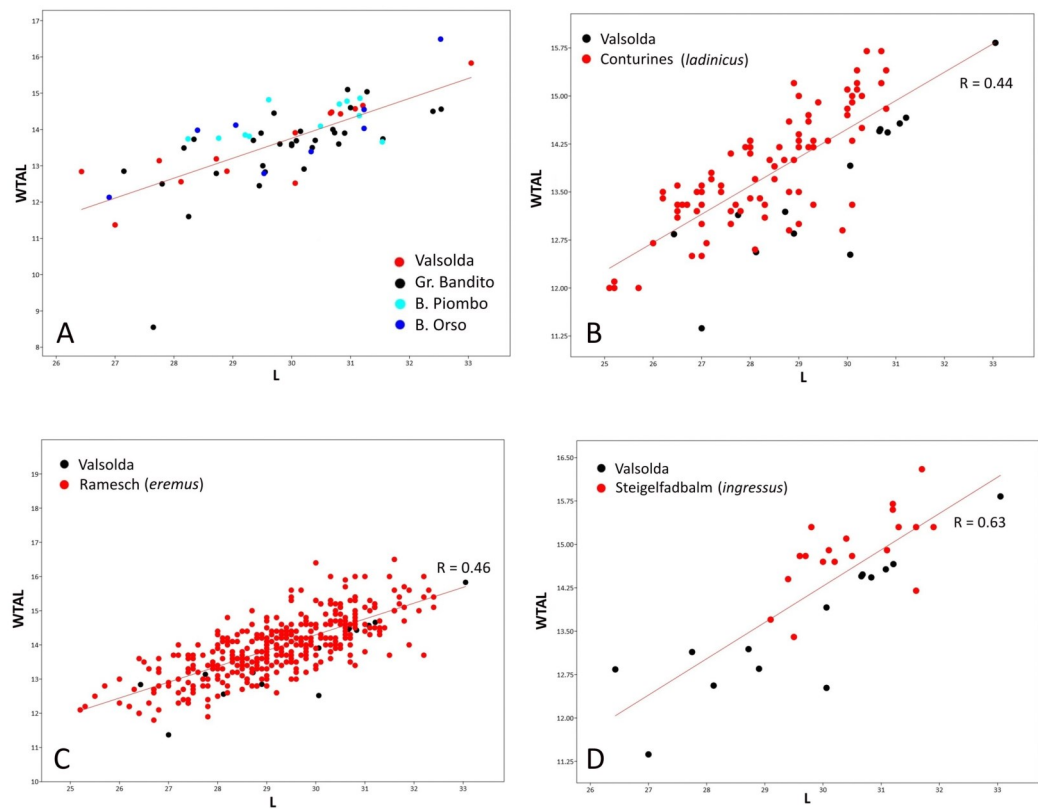
Fig. 3: A: Length-Width (WTAL) relationship in bears from Valsolda and some Italian cave bears. B-C-D: Length-Width (WTAL) relationship in a comparison between the cave bears from Valsolda and the *U. s. ladinicus* from Conturines (B), from Valsolda and *U. s. eremus* from Ramesch (C) and from Valsolda and *U. ingressus* from Steigelfadbalm (D). | **Abb. 3**: A: Verhältnis Länge-Breite (WTAL) bei Bären aus Valsolda und einigen italienischen Höhlenbären. B-C-D: Längen-Breiten-Verhältnis (WTAL) im Vergleich zwischen den Höhlenbären aus Valsolda und *U. s. ladinicus* aus Conturines (B), aus Valsolda und *U. s. eremus* aus Ramesch (C) und aus Valsolda und *U. ingressus* aus Steigelfadbalm (D).
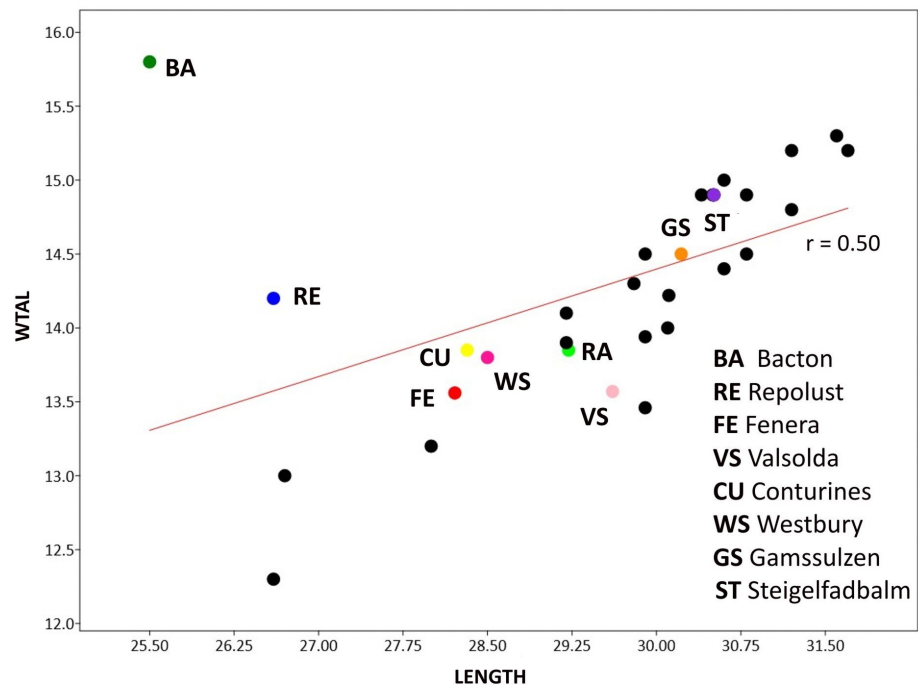

Fig. 4: Length-Width (WTAL) relationship in different taxa of cave bears from different localities from Italy and Europe. | **Abb. 4**: Längen-Breiten-Verhältnis (WTAL) bei verschiedenen Taxa von Höhlenbären aus verschiedenen Lokalitäten in Italien und Europa.
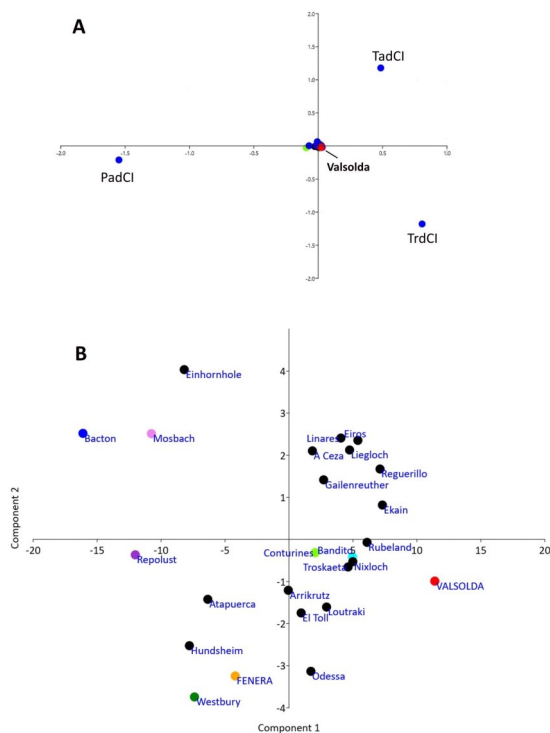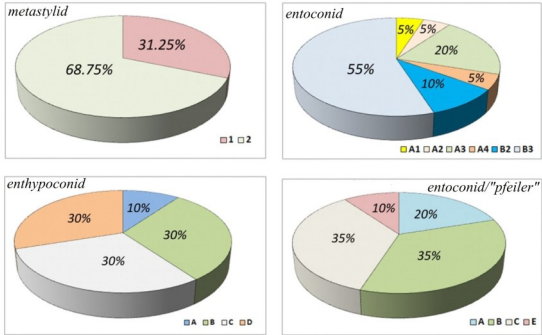
Fig. 5: A: Correspondence analysis (CA) utilizing the Grandal D'Anglade & López González (2004) indices between the cave bears from Valsolda and some Italian speleians. B: PCA analysis of the cave bears from different European and Italian localities. | **Abb. 5**: A: Korrespondenzanalyse (CA) unter Verwendung der Indizes von Grandal D'Anglade & López González (2004) zwischen den Höhlenbären von Valsolda und einigen italienischen Höhlenbewohnern. B: PCA-Analyse der Höhlen-bären aus verschiedenen europäischen und italienischen Lokalitäten.

Fig. 6: The different morphotypes and their frequencies in m₁ from Valsolda. | **Abb. 6**: Die verschiedenen Morphotypen und ihre Häufigkeit in m₁ aus Valsolda.

Spec.	metastylid	entoconid	enthypoconid	entoc. "*pfeiler*"
VS 6	1	B3	D	C
VS 7	1	A3	A	A
VS 8	1	A3	D	C
VS 9	1	B3	C	B
VS 10	1	A3	B	C
VS 11		B3	D	E
VS 12	1	A1	B	A
VS 13	2	A2	C	B
VS 14	1	B3	B	A
VS 15	1	B3	D	C
VS 16	2	B3	B	B
VS 17	2	A3	B	B
VS 18	1	A4	D	E
VS 19		B2	C	B
VS 20	1			
VS 21		B2	C	C
VS 22		B3	C	C
VS 23		B3	C	B
VS 24	2	B3	B	C
VS 25	1	B3	A	A
VS 26	2	B3	D	B

by the positions of bears that belonged to the *U. deningeri* (Bacton, Mosbach, Hundsheim, Westbury, Atapuerca) and *U. deningeroides* (Repolust) taxa, the second one made by those of the *U. spelaeus* s.l. taxon. Valsolda's position, although secluded, belongs within the second group.

There are two possible explanations for this. 1: the number of samples is too low, 2: these individuals represent the general characteristics of cave bears from North-Western Italy, an area shielded by the Alps from significative migrations of elements from other taxa (*U. ingressus*?). Another interesting aspect that can be deduced by observing **Fig. 5B** is that Valsolda, Mt. Fen-era, Conturines and Grotta del Bandito, this last in Piedmont region, sit in different positions. This could be a summary of the current situation in Northern Italy about the taxa and their evolu-tionary steps diversity as we know it now. To be more precise: the position in **Fig. 5B** of Mt. Fenera sits among the *U. deningeri/ deningeroides* caves and confirms the first results collected from the analyses of the incisors and premolars; this population had reached a low evolutionary step and may have belonged to *U. deningeri* (still to be confirmed), even if Podenzani et al. (2021) were inclined to put them within of the *U. s. eremus* taxon.

The position of the Conturines (South Tyrol) where *U. s. ladinicus*

used to live (around 2800 m a.s.l.) seems correct because these bears belonged to the »*spelaeus*« group despite having a smaller size, and, since they used to live at high altitudes, they developed unique features. Grotta del Bandito occupies a peculiar position because it is close to the Grotta della Basura (Liguria) where Quiles (2004) found cave bears with the highest morphodynam-ic indices for the P⁴/p₄ in Northern Italy. In a recent study on the P⁴/p₄ of the cave bears of Grotta del Bandito Santi & Rossi (2020) hypothesized a potential movement of »*ingressus*-like« bears from Grotta della Basura towards Grotta del Bandito be-cause of the relatively high frequency of morphotypes of com-plex tooth surfaces.

Morphodynamic analysis

It is based on defining and recognizing morphotypes following the Rabeder methodology (1999). In **Fig. 6** we show the percent-age distribution of the frequencies of the different morphotypes that refer to the different parts of the tooth surface of the m₁s: between the Metastylents 68.75% of the remains show the morphotype »1«, among the pfeiler Entoconids the frequency of the morphotypes is more fractioned: Morphotypes »B« and »C« represent 35% of the samples each, »A« is the 20% and »E« the 10%; 55% of the Entoconids shows intermediate morphotypes (»B3«); looking at the Entipoconids almost all of observed mor-photypes (90%) are either »B«, »C« or »D«. Beside one instance in

which morphotypes that showed greater complexity in the different components of the tooth's surface have been observed, the morphodynamic range of the m_1s is similar to the staple one observed in Italian cave bears.

Conclusion

With this study, based on morphometric and morphodynamic analyses of a sample of m_1s from Valsolda (Como, Lombardy), all of the teeth components have been studied, after a recent publication has been done about incisors, premolars and the remaining molars (Santi & Rossi, 2020). Collected data are similar to those from other sites of North-Western Italy and from these we can suppose that *U. ingressus* probably never made his way into Valsolda, even if his presence was found in Steigelfadbalm (Frischauf et al., 2017) and in North-Eastern Italy (Terlato et al., 2019). However, with the data currently available, there is no concrete proof of the presence of *U. ingressus* in other Alpine and Prealpine caves. It is necessary to admit that, for now, without chronological or genetic data it is impossible to put Valsolda's cave bears inside of a precise species or subspecies. Because of this it is confirmed what was already deduced with the study of the other teeth (Santi & Rossi, 2020), which is that they can only be put inside a more generic *U.* gr. *spelaeus*. An important element is given by the position of the Italian caves (Conturines, Valsolda, Grotta del Bandito, Mt. Fenera) in the PCA diagram of **Fig. 5B**; these well-defined fields layouts reflect very well the morphometric features of bears likely belonging to two or more different taxa.

From a morphodynamic perspective m_1s from Valsolda refer to a population with a medium evolutionary level, typical of cave bears from Northern Italy. These populations feature primitive and intermediate morphotypes, with very few elements that show more advanced features. Among all the populations of Northern Italy only the bears from Grotta della Basura (Liguria region) are an exception since they have the highest morphodynamic index for the P^4/p_4 teeth. Since this cave is close to the Grotta del Bandito, where some advanced morphotypes have been found, it is possible that the two populations met each other. It seems that this meeting (or crossbreed) did not happen with the bears from Valsolda.

Acknowledgment

Declaration of consent

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence this work. They are not conflicts of interest.

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