Observations on cranial and dental morphology of *Arvicola italicus* Savi, 1838 (Mammalia, Rodentia, Arvicolinae)

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Abstract. Recent genetic studies have shown that, almost all Italian populations previously attributed to *Arvicola amphibius* belong to a new species: *A. italicus*. The purpose of this work is to start characterising the Italian populations of *Arvicola* with regard to cranial morphometry and to the aspect of upper incisors. Through a comparison with specimens of *A. amphibius*, of *A. monticola* and of *A. sapidus*, the species *A. italicus* results altogether more similar to *A. sapidus*.

Key words. *Arvicola*, morphology, systematics, Italy.

1. Introduction

The genus *Arvicola* has undergone complex taxonomic incidents with regard to the validity of species and subspecies (Cagnin 2008b) and therefore *A. amphibius* (Linnaeus, 1758) has been reported as a species with wide Euroasiatic distribution (Musser & Carleton 2005) until recently. These same authors examining other works on morphology and genetics have proposed to consider the fossorial form (distributed from Spain to Romania) as the good species: *A. scherman* (Shaw, 1801), according with other previous authors. Afterwards, Kryštufek et al. (2015), on the basis of mitochondrial cytochrome *b* (cyt *b*) gene sequences, have shown that *A. scherman* is not a monophyletic *taxon* and the Bayesian inference tree obtained from their analysis highlighted that the aquatic and fossorial forms are mixed, without forming distinct clades, while Pardiñas et al. (2017) attributed to *A. monticola* de Sélys-Longchamps, 1838 the fossorial forms present from the Cantabrian mountains to Pyrenees and on the French and Swiss Alps.

As for the Italian specimens of the genus *Arvicola*, both in the aquatic and fossorial form, Castiglia et al. (2016), on the basis of mt DNA, have detected a divergent lineage and placed them in a new species whose available name according to Gippoliti (2012) is *A. italicus* Savi, 1838, *taxon* originally described as *A. amphibius* var. *italica* (Savi 1838). Moreover Castiglia et al. (2016) agreed with Kryštufek et al. (2015) on the status of fossorial forms. The monophyly of *A. italicus* is also confirmed by Mahmoudi et al. (2019). According to these authors on the basis of fossil data starting from the Pleistocene species *Mimomys savini*, the lines that would bring to *A. amphibius* on one side and to *A. italicus and A. monticola* on the other one separated 0.671 Ma, while the two last mentioned species would start to differentiate 0.441 Ma.

A. italicus is distributed, even though in an irregular way, in the whole continental Italy where several cases of extinction and rarefaction have been documented (Nappi 2004, Cagnin 2008a). The presence of a mt DNA haplotype found in southern Swiss belonging to the Italian clade (Brace et al. 2016), suggests presence of *A. italicus* outside the political borders of Italy, therefore Amori & Castiglia (2018) propose the status of "near-endemic" among the mammals of Italian fauna. With regard to Sicily, Pasa (1959) reported records of the species on the basis of bone findings and observation of lairs, but afterwards it was reputed more plausible to consider the bones as fossils and the lairs as the product of *Microtus nebrodensis*. Consequently, the presence on the island in recent times has been excluded (Catalisano & Sarà 1995). The recent check-list of Italian mammals (Loy et al. 2019) reports two species of the genus *Arvicola*: *A. amphibius* and *A. italicus*, the former one present only in the North-East, but further investigations are needed to clarify its distribution and the possible contact areas with *A. italicus*.

Fossorial forms in Italy have been reported in the north-eastern portion (Lapini & Paolucci 1994) and in Piedmont (Capizzi & Santini 2007).

Considering the complex systematics of the genus *Arvicola* and the recent acquisitions about the Italian populations, in the present paper we wish to present pertinent considerations about cranial and dental characters.

2. Materials and methods

We examined 78 Italian specimens of *Arvicola* that, according to the cited recent acquisitions, can be attributed to *A. italicus*. These specimens have been compared with 43 skulls of *A. sapidus,* 73 of *A. amphibius* and 151 of *A. monticola*, from pellets of Strigiformes collected in France.

The skulls of *A. italicus* are deposited in the following collections: Civic Museum of Natural History, Milan (13 specimens from Piedmont, 10 from Lombardy, 1 from Tuscany, 1 from Latium and 1 from Calabria), Civic Museum of Natural History, Morbegno (Sondrio) (5 specimens from Lombardy), Florence University Natural History Museum, Zoology Section "La Specola" (12 specimens from Tuscany, 3 from Lombardy, 2 from Emilia Romagna, 2 from Apulia, 1 from Campania, 1 from Calabria), Zoology Museum I.S.P.R.A, in Ozzano Emilia (Bologna) (7 specimens from Molise, 6 from Emilia Romagna, 4 from the Abruzzi), Natural History Gallery of Casalina di Deruta (Perugia) (2 specimens from Umbria), the private collections A. Gaggi-A.M. Paci at Città di Castello (Perugia) (3 specimens from Umbria and 1 from the Abruzzi) and F. Ricci at Rapino (Chieti) (3 specimens from the Abruzzi). The French material used as comparison sample and preserved in the collection Gaggi-Paci was collected and donated by Xavier Birot-Colomb, Patrick Brunet-Lecomte, Jean Chevallier, Nathalie Indelicato, Damien Lerat and Jean-François Noblet.

Three publications considering the differences between *Arvicola amphibius* sensu lato and *A. sapidus* have been taken into consideration (Table 1). We have mentioned them as "Arvicola amphibius sensu lato", since these works were produced before the recent discoveries in systematics and taxonomy, so under the taxon *A. amphibius*, *A.italicus* and *A. monticola* are included.

The analysed morphological characters on the examined skulls are the following: upper incisors, articular and angular mandibular apophysis, position of mandibular foramen with regard to the incisor's root and to the apophysis, anterior loop of the first lower molar (Figs 1-4).

As for the cranial morphometry, the measurements reported in Fig. 5 (redrawn from Garde & Escala 1997, Ventura 2004) were taken and from them the following indices have been proposed:

cranial index' (CBL/ CH) ;
cranial index" (CBL/ZW);
rostral index (RZ/NW);
index of nasal bones lengthening (NL/NW);
mandibular index (ML/HC).

Each variable was analysed with two-way analysis of variance (ANOVA-2): taxon (four classes: *ampbibius*, *italicus*, *monticola* and *sapidus*) and age (2 classes: juvenile and adult), completed in case of significant inter-

Table 1. Distinctive characters between *Arvicola amphibius* s.l. and *A. sapidus* as considered by some authors. We have mentioned *Arvicola amphibius* as "*sensu lato*", since these works were edited before the recent discoveries in systematics and taxonomy, so under *Arvicola amphibius* taxon, *A. italicus* and *A. monticola* should be also considered.

	Arvicola amphibius s.l.	*Arvicola sapidus*
Chaline et al. 1974	width of nasal bones <4.5 mm, diastema <13 mm upper incisors very projected forward, rounded M_1 anterior loop	width of nasal bones >4.5 mm, diastema 13-15 mm upper incisors not projected forward, M_1 anterior loop with acute angle on the inner edge
Reichstein 1982	head-body length <165 mm, tail <75 mm, back foot <26 mm, weight <100 g width of nasal bones <4.6 mm, mandibular foramen on the side of the incisor's root (like *Microtus arvalis*)	head-body length >165 mm, tail >100 mm, back foot>30 mm, weight >100 g width of nasal bones>4.6 mm almost as the rostrum's width, mandibular foramen next to the incisor's root (like in *Microtus agrestis*)
Le Louarn & Quéré 2003	back foot <31 mm mandibular foramen before the incisor's root and at the level of the two apophisis' junction, proodont upper incisors, rounded M_1 anterior loop	back foot >32 mm mandibular foramen on the incisor's root and lower than the two apophysis' junction, orthodont upper incisors, M_1 anterior loop with acute angle on the inner edge

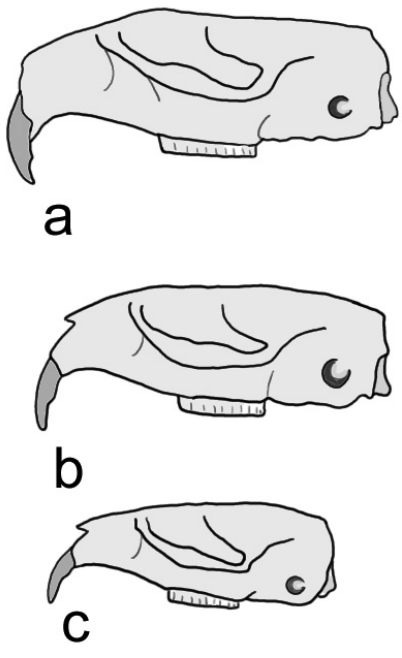


Fig. 1. Skulls' lateral view of *Arvicola sapidus* (a), *Arvicola amphibius* aquatic form (b), *Arvicola amphibius* group fossorial form* (c) (redrawn from Reichstein 1982). * Quotated as *Arvicola terrestris exitus* in the original paper.

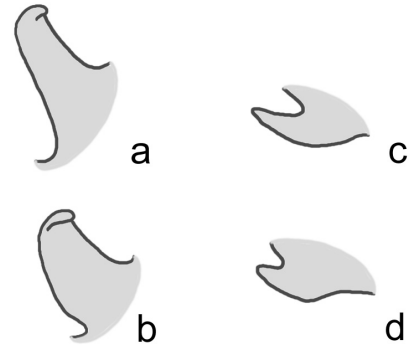


Fig. 2. Mandibular articular processes: straight or slightly concave (a) and convex (b), angular process slender (c) and stubby (d).

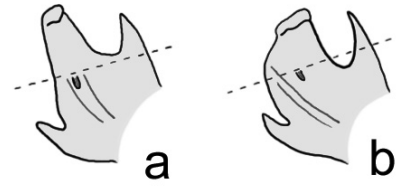


Fig. 3. Details of the rear side of the left hemimandible, in lingual view, of *A. sapidus* (a) and of *A. amphibius* (b) (redrawn from Le Louarn & Quéré 2003); the dashed line indicated the position of foramen compared to the socket between coronoid process and the angular one.

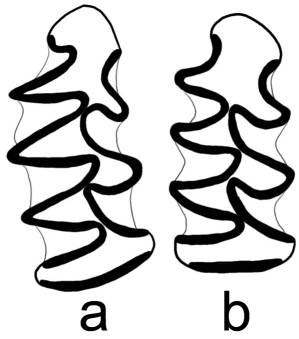


Fig. 4. Right first lower molars of adult *A. sapidus* (a, coll. A. Gaggi-A.M. Paci ArSCH01) and of adult *A. amphibius* (b, coll. A. Gaggi-A.M. Paci AACB10); the anterior loops are marked.

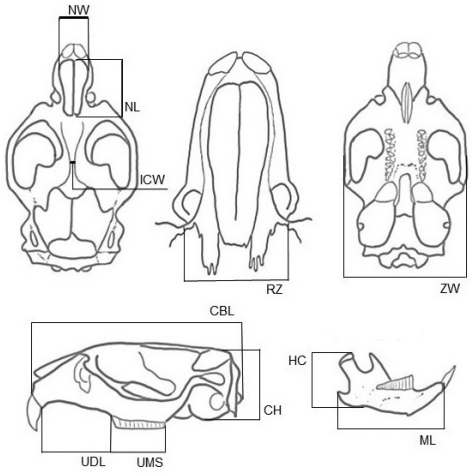


Fig. 5. Skull measurements carried out in this study. CBL = condylobasal length; UDL = upper diastema length; NL = nasal length; ZW = zygomatic width; CH = cranial height; NW = nasal width; ICW = interorbital crests width; RZ = rostral-zygomatic junction width; UMS = upper molar series; ML = mandible length; HC = mandible height (redrawn from Garde & Escala 1987; Ventura 2004).

action taxon-age with two one-way analysis of variance, the taxon (ANOVA-1), one per each age class. In case of a significant taxon effect, a Bonferroni's test of multiple comparisons was performed in order to ascertain between which taxa, taken two by two, a significant difference was observed. The risk of first species was fixed at 5%.

On the analysed skulls it was then possible to estimate the age classes. The criteria used by Garde et al. (1993), Ventura (1993-1994), Garde & Escala (1997) for *A. sapidus* and *A. monticola* were also successfully used for *A. amphibius* and *A. italicus*. These authors consider 6 age classes: 0 (0-3 weeks), I (3-6 weeks), II (6-10 weeks), III (10-14 weeks), IV (3-9 months), V (beyond 9 months). In our research we have listed the immature specimens (classes 0-I-II) in group "A" and those sexually mature (classes III-IV-V) in group "B". On attributing age classes it was also calculated, when possible, a cranial index following the formula IC=ICW/CBLx100 (cf. Garde et al. 1993) that tends to progressively decrease to 0, as with the ageing the interorbital crests draw near till fusion.

Finally, a different approach was taken with two specimens preserved in the Natural History Gallery of Casalina di Deruta. As they are naturalized specimens, it was not possible to analyse the skull, so x-rays were taken (Gaggi & Paci 2011) to get at least some general indications on their morphology; they are in fact interesting findings both from a faunal and from an historical point of view, as they come from the Lake Trasimeno (Umbria), where the species used to live at least until a century ago and it was not found again in recent times (Gaggi & Paci 2014).

Not all skulls are complete or intact and for this reason the above described operations have not always been possible; thus for each

Table 2. Morphology of upper incisors (a orthodont, b slightly proodont, c proodont, see Fig. 1) in *Arvicola italicus* (*A. i.*), *A. amphibius* (*A. a.*), *A. monticola* (*A. m.*) and *A. sapidus* (*A. s.*). A = age class immature; B = age class sexually mature; N = total number of specimens.

	N	a	b	c	other
A. i. A	21	15	6	\	\
A. i. B	24	18	6	\	\
A. a. A	21	1	14	6	\
A. a. B	32	\	15	17	\
A. m. A	55	\	9	46	\
A. m. B	29	\	7	22	\
A. s. A	21	15	6	\	\
A. s. B	5	5	\	\	\

Table 3. Articular processes in mandible straight or slightly concave (a) and convex (b) (see Fig. 2) in *Arvicola italicus* (*A. i.*), *A. amphibius* (*A. a.*), *A. monticola* (*A. m.*) and *A. sapidus* (*A. s.*); A = age class immature; B = age class sexually mature; N = total number of specimens.

	N	a	b	other
A. i. A	24	24	\	\
A. i. B	24	24	\	\
A. a. A	17	1	16	\
A. a. B	32	10	22	\
A. m. A	68	3	65	\
A. m. B	21	4	17	\
A. s. A	28	27	1	\
A. s. B	7	5	2	\

Table 4. Angular processes in mandible: slender (a) and stubby (b) (see Fig. 2) in *Arvicola italicus* (*A. i.*), *A. amphibius* (*A. a.*), *A. monticola* (*A. m.*) and *A. sapidus* (*A. s.*); A = age class immature; B = age class sexually mature; N = total number of specimens.

	N	a	b	other
A. i. A	21	4	10	7 intermediate
A. i. B	23	18	3	2 intermediate
A. a. A	16	1	15	\
A. a. B	32	11	21	\
A. m. A	66	2	64	\
A. m. B	21	2	19	\
A. s. A	27	23	4	\
A. s. B	4	4	\	\

Table 5. Mandibular *foramen* as *Microtus agrestis* (a), as *M. arvalis* (b) (see Fig. 3) in *Arvicola italicus* (*A. i.*), *A. amphibius* (*A. a.*), *A. monticola* (*A. m.*) and *A. sapidus* (*A. s.*); A = age class immature; B = age class sexually mature; N = total number of specimens.

	N	a	b	other
A. i. A	25	20	4	1 intermediate
A. i. B	24	15	8	1 intermediate
A. a. A	18	6	12	\
A. a. B	33	10	23	\
A. m. A	67	7	60	\
A. m. B	21	3	18	\
A. s. A	28	28	\	\
A. s. B	6	3	3	\

Table 6. Presence of anterior loop with inner (a) or rounded (b) acute angle in the first lower molar (see Fig. 4) in *Arvicola italicus* (*A. i.*), *A. amphibius* (*A. a.*), *A. monticola* (*A. m.*) and *A. sapidus* (A. s.).; A = age class immature; B = age class sexually mature; N = total number of specimens.

	N	a	b	other
A. i. A	24	14	4	6 intermediate
A. i. B	27	\	25	2 intermediate
A. a. A	14	4	7	3 intermediate
A. a. B	20	\	16	4 intermediate
A. m. A	42	4	34	4 intermediate
A. m. B	14	\	14	\
A. s. A	18	18	\	\
A. s. B	3	2	\	1 intermediate

analysis the number of the used specimens is indicated. The cranial measurements have been performed by A. Gaggi, A. Nappi and A. M. Paci; the statistical analysis have been elaborated by P. Brunet-Lecomte; the illustrations are drawn by A. Nappi, derived from photographic material by Mario Andreini and A. Nappi. All authors have contributed to the elaboration and to the discussion of the texts.

3. Results

The results of the morphological analysis are synthesized in the Tables 2-6, the ones of the measurement in the Tables 7-26. A small sample of the analysed specimens is shown in Figs 6-9.

The results of the measurements and ratios are listed below.

CBL - Condylobasal length (Tables 7, 9 and 26): a significant taxon-age interaction has been found. No difference has been found among the taxa of the juveniles. For the adults a significant difference two by two has been found among all taxa, with the exception of *A. italicus* and *A. sapidus* characterized by a high CBL index. The least value CBL has been observed in *A. monticola*.

ICW - Interorbital crest width (Tables 7, 10 and 26): a significant taxon-age interaction has been found. No difference has been

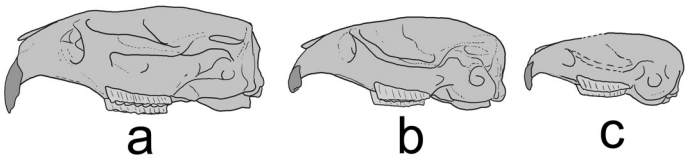


Fig. 6. Skulls of adult (a), subadult (b) and juvenile (c) of *A. italicus*. a: Apulia, Cerignola (FG); Museum "La Specola", Florence n. 5603. b: Lombardy, Merate (LC); Museum "La Specola", Florence, n. 6055. c: Tuscany, Capalbio (GR); Museum "La Specola", Florence, n. 6047.

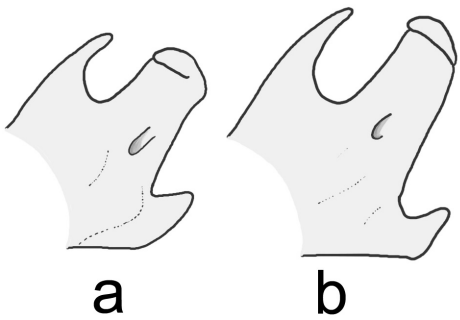


Fig. 7. Details of the rear side of the right hemimandible, in lingual view, of *A. italicus*. Juvenile (a): Piedmont, Racconigi (CN); Civic Museum of Natural History of Milan, n. 1869. Adult (b): Lombardy, Sartirana (PV); Civic Museum of Natural History of Milan, n. 6652.

found among the taxa of the adult individuals. For juveniles a significant difference two by two has been found among *A. sapidus* characterised by a high ICW index and *A. amphibius* and *A. monticola* characterized by a reduced ICW index, where no difference has been noted between *A. sapidus* and *A. italicus*.

UDL - Upper diastema length (Tables 7, 11 and 26): a significant taxon-age interaction has been found. No difference has been found among the taxa of the juveniles. In the adults a significant difference two by two has been found among *A. italicus* characterized by a high UDL and *A. amphibius, A. monticola* and *A. sapidus* characterized by a medium or reduced UDL. *A. amphibius* has a bigger UDL than *A. monticola*.

UMS - Upper molar series (Tables 8, 12 and 26): a non-significant taxon-age interaction has been found. *A. amphibius*, *A. italicus* and *A. monticola* are different two by two with high UMS index in *A. italicus*, moderate in

Table 7. Comparison of measures showing a significant taxon-age interaction (p< 5%). # = difference, Nb # = number of differences; A = age class immature; B = age class sexually mature.

Measure	ANOVA-2			ANOVA-1		Multiple two by two comparison (adjusted p)					
	Taxon	Age	Inter	Age	Taxon	*am* vs. *it*	*am* vs. *mo*	*am* vs. *sa*	*it* vs. *mo*	*it* vs. *sa*	*mo* vs. *sa*
CBL	**p<0.0001**	**p<0.0001**	**p<0.0001**	A	p=0.1704	p=1.0000	p=1.0000	p=0.7192	p=1.0000	p=0.4008	p=0.1889
				B	**p<0.0001**	**p<0.0001**	**p<0.0001**	**p<0.0001**	**p<0.0001**	p=1.0000	**p<0.0001**
ICW	**p<0.0001**	**p<0.0001**	**p=0.0299**	A	**p<0.0001**	p=0.1224	p=1.0000	**p=0.0006**	**p=0.0024**	p=0.5834	**p<0.0001**
				B	p=0.1031	p=1.0000	P=1.0000	p=0.0909	p=1.0000	p=0.2493	p=0.1459
UDL	p=0.2520	**p<0.0001**	**p=0.0001**	A	p=0.0785	p=1.0000	p=0.5746	p=1.0000	p=0.7859	p=1.0000	p=0.1428
				B	**p<0.0001**	**p=0.0224**	**p=0.0043**	p=1.0000	**p<0.0001**	p<0.0730	**p<0.0001**
ML	**p<0.0001**	**p<0.0001**	**p=0.0011**	A	**p<0.0001**	**p=0.0374**	p=1.0000	**p=0.0016**	**p=0.0030**	p=1.0000	**p<0.0001**
				B	**p<0.0001**	**p<0.0001**	**p=0.0045**	**p=0.0039**	**p<0.0001**	p=1.0000	**p<0.0001**
HC	**p<0.0001**	**p<0.0001**	**p=0.0004**	A	**p<0.0001**	p=1.0000	p=1.0000	**p<0.0001**	p=1.0000	**p<0.0001**	**p<0.0001**
				B	**p<0.0001**	**p<0.0001**	p=1.0000	**p<0.0001**	**p<0.0001**	p=0.0584	**p<0.0001**
CH	**p<0.0001**	**p<0.0001**	**p<0.0001**	A	p=0.1492	p=0.4236	p=1.0000	p=1.0000	p=0.9843	p=0.7396	p=1.0000
				B	**p<0.0001**	**p<0.0001**	**p=0.0241**	**p=0.0033**	**p<0.0001**	p=0.7136	**p=0.0002**
ZW	**p<0.0001**	**p<0.0001**	**p=0.0260**	A	**p=0.0007**	**p=0.0178**	p=1.0000	p=1.0000	**p=0.0003**	**p=0.0188**	p=1.0000
				B	**p<0.0001**	**p<0.0001**	**p<0.0001**	p=0.2470	**p<0.0001**	p=1.0000	**p<0.0001**
IC	**p=0.0141**	**p<0.0001**	**p=0.0003**	A	**p=0.0067**	**p=0.0239**	p=1.0000	p=1.0000	**p=0.0112**	p=1.0000	p=1.0000
				B	p=0.0865	p=1.0000	p=1.0000	p=0.2506	p=1.0000	p=0.0857	p=0.6114
Nb # A						3	0	3	4	2	3
Nb # B						6	5	4	6	0	6

A. amphibius and reduced in *A. monticola*. The small number of specimens of *A. sapidus* has not allowed an evaluation of the comparison two by two.

ML - Mandible length (Tables 7, 13 and 26): a significant taxon-age interaction has been found. In juveniles and in adults ML is higher in *A. italicus* and *A. sapi-*

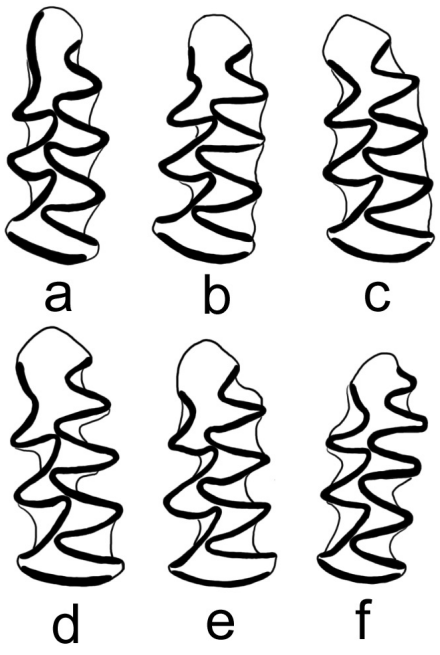


Fig. 8. First left lower molars of juveniles of *A. italicus*. (a): Piedmont, Gavi (AL); Civic Museum of Natural History of Milan, n. 1860. (b): Molise, San Vito Creek (CB); I.S.P.R.A., n. 4370. (c): Molise, Biferno River (CB); I.S.P.R.A., n. 4372. (d): The Abruzzi, Bussi sul Tirino (CH); Ricci coll. n. AIBT01. (e): Umbria, Borgo Trevi (PG); Gaggi-Paci coll., n. AIBTR01. (f): The Abruzzi, Bussi sul Tirino (CH); Gaggi-Paci coll., n. AIBT04.

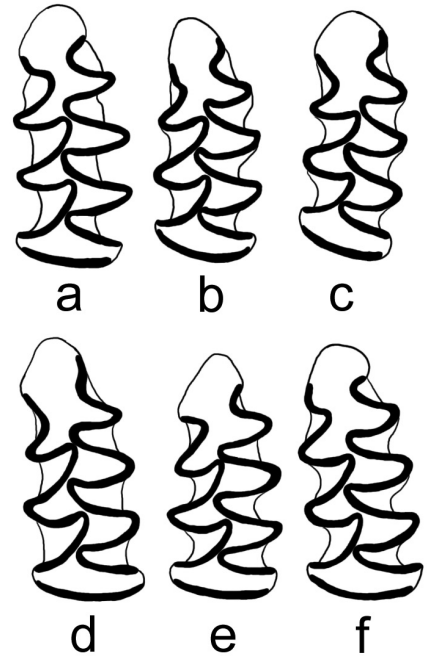


Fig. 9. First left lower molars of adult specimens of *A. italicus*. (a): Lombardy, around Milan; Civic Museum of Natural History of Milan, n. 1861. (b): Molise, Trigno River (CB); I.S.P.R.A., n. 4366. (c): the Abruzzi, Pescara River; I.S.P.R.A., n. 4367. (d): Apulia, Cerignola (FG); Civic Muserum of Natural history of Milan, n. 5602. (e): Tuscany, around Pisa; Museum "La Specola", Florence, n. 6058. (f): Lombardy, Sartirana (PV); Civic Museum of Natural History of Milan, n. 6652.

Table 8. Comparison of variables showing a not significant taxon-age interaction (p≥ 5%). Nb# = number of differences; ** analysis performed excluding *A. sapidus* (one record only).

Variable	ANOVA-2			Multiple two by two comparison (adjusted p)					
	Taxon	Age	Interaction	*am* vs. *it*	*am* vs. *mo*	*am* vs. *sa*	*it* vs. *mo*	*it* vs. *sa*	*mo* vs. *sa*
UMS	**p<0.0001**	**p<0.0001**	p=0.1473	**p<0.0001**	**p=0.0007**	NE	**p<0.0001**	NE	NE
RZ	**p< 0.0001**	**p< 0.0001**	p=0.3988	**p=0.0085**	**p<0.0001**	p=1.0000	**p<0.0001**	p=1.0000	**p<0.0001**
NL	**p=0.0035**	**p=0.0086**	p=0.1579	p=0.1641	p=0.9075	p=1.0000	**p=0.0049**	p=1.0000	p=0.8033
NW	**p< 0.0001**	p=0.1021	p=0.6908	**p=0.0002**	p=1.0000	P=0.2007	**p=0.0002**	p=1.0000	p=0.0895
CBL/CH**	p=0.0485	p=0.4118	p=0.2480	P=0.0423	P=02384	-	P=0.8787	-	-
CBL/ZW	**p<0.0001**	p=0.7139	p=0.9656	**p=0.0425**	p=1.0000	**p=0.0006**	**p=0.0240**	p=0.1469	**p=0.0035**
RZ/NW	**p=0.0014**	p=0.8767	p=0.7569	**p=0.0401**	p=1.0000	p=0.5692	**p=0.0068**	p=1.0000	p=0.1728
NL/NW	**p=0.0003**	p=0.6031	p=0.5714	**p=0.0023**	p=1.0000	**p=0.0429**	**p=0.0204**	p=1.0000	p=0.0700
ML/HC	**p=<0.0001**	p=0.1085	p=0.1832	**p=0.0156**	p=1.0000	p=0.1683	**p=0.0009**	**p=0.0001**	p=0.2847
Nb #				8	2	2	8	1	2

Table 9. Description of the condylobasal length (CBL) measurements according to age and taxon.

Age	Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
A	amph	6	31.805	1.251	0.511	31.930	30.210	33.440
	ital	15	31.468	4.908	1.267	31.210	22.850	38.800
	mont	34	30.900	1.621	0.278	31.065	24.630	34.100
	sapi	2	35.490	0.424	0.300	35.490	35.190	35.790
B	amph	29	34.104	1.246	0.231	33.730	32.640	37.200
	ital	24	37.188	1.439	0.294	37.235	34.900	39.480
	mont	26	32.150	1.433	0.281	32.205	29.400	34.700
	sapi	6	37.708	1.404	0.573	37.965	35.670	39.360

Table 10. Description of the interorbital crests width (ICW) measurements according to age and taxon.

Age	Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
A	amph	22	1.880	0.626	0.133	1.515	1.200	3.320
	ital	21	2.314	0.887	0.194	2.180	1.320	4.770
	mont	56	1.749	0.491	0.066	1.625	1.030	3.220
	sapi	21	2.627	0.515	0.112	2.780	1.780	3.420
B	amph	33	0.538	0.369	0.064	0.500	0.000	1.280
	ital	38	0.616	0.496	0.081	0.470	0.000	1.520
	mont	31	0.569	0.240	0.043	0.550	0.000	1.080
	sapi	6	0.987	0.667	0.272	1.240	0.000	1.590

Table 11. Description of the upper diastema length (UDL) measurements according to age and taxon.

Age	Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
A	amph	23	10.169	1.176	0.245	10.270	7.500	12.750
	ital	17	10.164	1.786	0.433	9.950	6.500	13.260
	mont	56	10.612	0.806	0.108	10.780	8.140	12.250
	sapi	22	9.998	0.760	0.162	9.955	8.790	11.770
B	amph	33	11.990	0.469	0.082	11.890	11.270	13.030
	ital	29	12.452	0.591	0.110	12.600	11.250	13.600
	mont	31	11.455	0.727	0.131	11.460	10.000	12.880
	sapi	5	11.696	0.779	0.348	11.660	10.690	12.830

Table 12. Description of upper molar series (UMS) measurements according to taxon.

Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
amph	40	8.101	0.516	0.082	8.090	7.120	9.110
Ital	45	8.832	0.827	0.123	8.810	6.120	10.160
mont	45	7.644	0.408	0.061	7.690	6.790	8.270
sapi	6	8.767	0.802	0.327	8.720	7.750	9.940

dus than in *A. amphibius* and *A. monticola*. On the contrary in the adults, ML is more reduced in *A. monticola* than in *A. amphibius*.

HC - Mandible height (Tables 7, 14 and 26): a significant taxon-age interaction has been found. In juveniles, HC is higher in *A. sapidus* than in the three other taxa. In

Table 13. Description of mandible length (ML)measurements according to age and taxon.

Age	Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
A	amph	17	19.641	1.358	0.329	19.690	16.660	22.070
	ital	29	21.016	2.502	0.465	20.720	15.840	25.930
	mont	63	19.718	1.136	0.143	19.840	16.000	22.080
	sapi	27	21.517	1.536	0.296	21.910	18.350	24.200
B	amph	31	22.349	0.771	0.138	22.260	20.050	24.340
	ital	33	24.670	1.227	0.214	24.640	22.470	27.840
	mont	21	21.282	0.999	0.218	21.240	18.580	23.280
	sapi	4	24.378	2.065	1.032	24.595	22.060	26.260

Table 14. Description of mandible height (HC) measurements according to age and taxon.

Age	Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
A	amph	19	9.729	0.854	0.196	9.930	8.310	11.370
	ital	29	9.763	0.941	0.175	9.680	8.300	11.670
	mont	66	9.650	0.791	0.097	9.670	7.630	11.330
	sapi	26	10.967	0.760	0.149	10.855	9.730	12.330
B	amph	32	10.936	0.557	0.099	10.820	10.000	11.910
	ital	34	12.050	1.237	0.212	12.335	9.490	13.970
	mont	23	10.774	0.602	0.126	10.900	9.280	11.600
	sapi	7	13.059	1.284	0.485	12.900	11.100	15.130

Table 15. Description of rostralzygomatic junction width (RZ) measurements according to taxon.

Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
amph	53	5.087	0.490	0.067	5.090	4.070	6.550
ital	55	5.370	0.783	0.106	5.380	1.800	6.670
mont	85	4.583	0.356	0.039	4.550	3.950	5.430
sapi	25	5.081	0.338	0.068	5.010	4.540	5.830

Table 16. Description of nasal length (NL) measurements according to taxon.

Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
amph	14	9.002	0.556	0.148	8.915	8.220	10.280
ital	42	9.683	0.931	0.144	9.915	7.560	11.480
mont	7	8.401	0.932	0.352	8.910	6.810	9.130
sapi	3	9.497	1.289	0.744	9.090	8.460	10.940

the adults, HC is higher in *A. sapidus* and A. *italicus* than in *A. amphibius* and *A. monticola*.

RZ - Rostralzygomatic junction width (Tables 8, 15 and 26): the taxon-age interaction was not significant. *A. italicus*, characterized by a high value, is different from *A. amphibius* and *A. monticola*, characterized by a medium and reduced value, respectively. On the other hand, *A. monticola* is different from *A. amphibius* and *A. sapidus*, characterized by a medium value.

NL - Nasal length (Tables 8, 16 and 26): the taxon-age interaction was not significant.

Table 17. Description of the nasal width (NW) measurements according to taxon.

Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
amph	14	3.684	0.253	0.068	3.740	3.200	4.030
ital	46	4.583	0.720	0.106	4.745	2.980	6.390
mont	7	3.410	0.443	0.168	3.540	2.630	3.820
sapi	3	4.743	0.755	0.436	4.720	4.000	5.510

Table 18. Description of cranial height (CH) measurements according to age and taxon.

Age	Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
A	amph	5	10.600	0.693	0.310	10.320	10.000	11.640
	ital	16	11.450	1.341	0.335	11.440	9.080	13.060
	mont	25	11.044	0.481	0.096	11.190	10.240	12.100
	sapi	1	10.000	-	-	10.000	10.000	10.000
B	amph	24	11.785	0.521	0.106	11.695	11.030	12.880
	ital	25	13.086	0.716	0.143	13.090	11.630	14.370
	mont	22	11.238	0.612	0.130	11.445	9.490	12.070
	sapi	1	14.090	-	-	14.090	14.090	14.090

Table 19. Description of the zygomatic width (ZW) measurements according to age and taxon.

Age	Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
A	amph	15	19.503	1.292	0.334	19.120	18.040	22.400
	Ital	9	21.026	1.566	0.522	20.770	18.900	23.210
	mont	34	19.106	1.007	0.173	19.245	16.960	21.790
	sapi	13	19.469	1.132	0.314	19.310	17.630	21.500
B	amph	32	21.281	0.835	0.148	21.160	19.660	22.990
	ital	22	22.774	1.027	0.219	22.870	20.630	24.460
	mont	23	20.080	0.947	0.198	20.110	18.300	21.970
	sapi	5	22.198	0.751	0.336	22.350	21.300	22.950

Table 20. Description of the cranial index (IC) measurements according to age and taxon.

Age	Taxon	N	Mean	Std Dev	Std Error	Median	Mini	Max
A	amph	6	4.492	0.704	0.287	4.285	3.770	5.720
	ital	14	7.194	2.707	0.723	7.210	4.160	12.420
	mont	34	5.280	1.529	0.262	4.675	3.450	9.580
	sapi	2	5.535	0.799	0.565	5.535	4.970	6.100
B	amph	31	1.597	1.124	0.202	1.490	0.000	3.750
	ital	26	1.354	1.298	0.255	5	0.000	4.020
	mont	26	1.797	0.806	0.158	1.780	0.000	3.270
	sapi	6	2.660	1.830	0.747	3.325	0.000	4.240

The comparison of the two by two means shows a significant difference between *A. italicus* characterized by a high value and *A. monticola* by a reduced value.

NW - Nasal width (Tables 8, 17 and 26): the taxon-age interaction was not significant. The two by two comparison of means shows a significant difference among *A.*

Table 21. Description of the CBL/CH ratio according to taxon.

Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
amph	29	2.911	0.151	0.028	2.930	2.619	3.182
ital	38	2.808	0.190	0.031	2.841	2.146	3.121
mont	47	2.838	0.214	0.031	2.858	2.147	3.330
sapi	1	2.727	.	.	2.727	2.727	2.727

Table 22. Description of the CBL/ZW ratio according to taxon.

Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
amph	34	1.598	0.050	0.009	1.600	1.493	1.712
ital	28	1.648	0.042	0.008	1.653	1.572	1.724
mont	48	1.608	0.071	0.010	1.607	1.448	1.784
sapi	7	1.714	0.032	0.012	1.723	1.675	1.761

Table 23. Description of the RZ/NW ratio according to taxon.

Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
amph	13	1.377	0.110	0.031	1.357	1.213	1.604
ital	43	1.204	0.169	0.026	1.211	0.941	1.689
mont	7	1.441	0.259	0.098	1.375	1.225	1.863
sapi	3	1.135	0.124	0.072	1.146	1.005	1.253

Table 24. Description of the NL/NW ratio according to taxon.

Taxon	N	Mean	Std Dev	Std Error	Median	Mini	Max
amph	14	2.449	0.144	0.039	2.422	2.285	2.734
ital	35	2.183	0.271	0.046	2.121	1.529	2.852
mont	7	2.471	0.104	0.039	2.492	2.342	2.594
sapi	3	2.009	0.097	0.056	1.985	1.926	2.115

Table 25. Description of the ML/HC ratio according to taxon.

Taxon	N	Mean	Std Dev	Std Error	Median	Min	Max
amph	48	2.030	0.083	0.012	2.019	1.881	2.233
ital	61	2.115	0.258	0.033	2.051	1.767	2.818
mont	83	2.023	0.097	0.011	2.015	1.833	2.252
sapi	30	1.949	0.090	0.016	1.967	1.716	2.140

italicus characterized by a high value and *A. monticola* by a reduced value. The scarce available material of *A. sapidus*, characterized by a high value, has not allowed us to highlight a difference with *A. monticola* and *A. italicus*.

CH - Cranial height (Tables 7, 18 and 26): a significant taxon-age interaction has been found. No significant difference has been found among the taxa in the juveniles. In adults CH is higher in *A. italicus* and *A. sapidus* than in *A. amphibius* and *A. monti-*

Table 26. Summary of similarities and differences in variables between *Arvicola italicus* and each other taxon (*A. amphibius*, *A. monticola* and *A. sapidus*). *A = age class immature; B = age class sexually mature. In a case of a significant interaction taxon-age, one-way ANOVA performed for each age class.

Variable	Age Class*	Mean value (higher, lower) in *Arvicola italicus* compared to other taxa in case of a significant difference (Bonferroni's test p<0.05)		
		italicus vs. *amphibius*	*italicus* vs. *monticola*	*italicus* vs. *sapidus*
Condylobasal length (CBL)	A	No difference	No difference	No difference
	B	Higher in *italicus*	Higher in *italicus*	No difference
Interorbital crests width (ICW)	A	No difference	Higher in *italicus*	No difference
	B	No difference	No difference	No difference
Upper diastema length (UDL)	A	No difference	No difference	No difference
	B	Higher in *italicus*	Higher in *italicus*	No difference
Upper molar series (UMS)	A+B	Higher in *italicus*	Higher in *italicus*	No difference
Mandible length (ML)	A	Higher in *italicus*	Higher in *italicus*	No difference
	B	Higher *italicus*	Higher in *italicus*	No difference
Mandible height (HC)	A	No difference	No difference	Lower in *italicus*
	B	Higher in *italicus*	Higher in *italicus*	No difference
Rostralzygomatic junction width (RZ)	A+B	Higher in *italicus*	Higher in *italicus*	No difference
Nasal length (NL)	A+B	No difference	Higher in *italicus*	No difference
Nasal width (NW)	A+B	Higher in *italicus*	Higher in *italicus*	No difference
Cranial height (CH)	A	No difference	No difference	No difference
	B	Higher in *italicus*	Higher in *italicus*	No difference
Zygomatic width (ZW)	A	Higher in *italicus*	Higher in *italicus*	Higher in *italicus*
	B	Higher in *italicus*	Higher in *italicus*	No difference
Cranial index (IC)	A	Higher in *italicus*	Higher in *italicus*	No difference
	B	No difference	No difference	No difference
CBL/CH	A+B	Lower in *italicus*	No difference	No difference
CBL/ZW	A+B	Higher in *italicus*	Higher in *italicus*	No difference
RZ/NW	A+B	Lower in *italicus*	Lower in *italicus*	No difference
NL/NW	A+B	Lower in *italicus*	Lower in *italicus*	No difference
ML/HC	A+B	Higher in *italicus*	Higher in *italicus*	Higher in *italicus*

cola which are also different between them and characterized by a medium and reduced value, respectively.

ZW - Zygomatic width (Tables 7, 19 and 26): a significant taxon-age interaction has been found. In juveniles class ZW is higher in *A. italicus* than in any of the other three taxa. In the adults ZW is higher in *A. italicus* than in *A. amphibius* and *A. monticola*. ZW is more reduced in *A. monticola* than in *A. sapidus* and *A. amphibius*.

IC - Cranial index (Tables 7, 20 and 26): a significant taxon-age interaction has been found. In juveniles class the IC index is higher in *A. italicus* than in *A. amphibius* and *A. monticola*. In the adults no two by two difference has been observed among the taxa.

CBL/CH (Tables 8, 21 and 26): only one taxon effect is reported. The two by two comparison of taxa shows a significant difference between *A. amphibius*, characterized by a high index and *A. italicus* characterized by a reduced index.

CBL/ZW (Tables 8, 22 and 26): only a taxon effect is reported. The two by two comparison of taxa shows a significant difference between *A. sapidus* and *A. italicus* on one side, characterized by a high index and *A. monticola* and *A. amphibius* on the other side, characterized by a reduced index.

RZ/NW (Tables 8, 23 and 26): only a taxon effect is reported. The two-by-two comparison of taxa shows a significant difference among *A. italicus* on one side, characterized by a reduced index and *A. monticola* and *A. amphibius* on the other side, characterized by a high index.

NL/NW (Tables 8, 24 and 26): only a taxon effect is reported. The two by two comparison of taxa shows a significant difference among *A. amphibius* on one side, characterized by a high index, and *A. italicus* and *A. sapidus* on the other side, characterized by a reduced index, beside a difference between *A. monticola* characterized by a high index and *A. italicus*.

ML/HC (Tabs. 8, 25 and 26): only a taxon effect is reported. The two by two comparison of taxa shows a significant difference among *A. italicus* on one side, characterized by a high ratio and the three other taxa on the other side, characterized by a reduced ratio.

4. Discussion

The innovation of the hypselodonty and the occurrence of the particular prismatic tooth in voles help them to face the glacial cycles and help them to succeed in the North (Renvoisé et al. 2009). According to Contoli et al. (1993), the tooth characters of the voles could be considered non adaptive and not influenced by environmental factors. These authors hypothesized that after reproductive isolation, environmental pressure selectively influences adaptive characters but, this same pressure has less effect on non-adaptive characters, such as the molar morphology, similarly to an isolated system subject to entropy laws.

Regarding the similarity in some specimens of *A. italicus* and of *A. sapidus* in the morphology of the anterior loop of the first lower molar, this is a consequence of the great variability of the molar morphology, as it can observed in many other species (e.g. *Chionomys nivalis* M_1 similar to *Microtus oeconomus* M_1), even when they are phylogenetically distant. Angermann (1974) has recognized the presence of similar tooth morphologies in the various species of voles, an example of Vavilov's law about the homologous series (Vavilov 1922). A significant example is represented by the similarity between *Microtus agrestis* and *M. arvalis*, recently highlighted by Navarro et al. (2018).

Some similarities between the *A. amphibius* group and *A. sapidus* can be deducted also from the iconography by Kryštufek & Vohralik (2005) based on Turkish specimens: the skulls of *A. amphibius,* represented in this paper in Figs 129-130, show the neatly orthodont incisors, while one of the two first lower molars in Fig. 133 shows a typical morphology of *A. sapidus* and the other one of *A. amphibius*. Also a part of the biometric values reported in that volume (for instance head-body length 151-205 mm, back foot length 29-39 mm, condyle length 36.3-43.0 mm), based on Turkish specimens and on one specimen from bordering areas near Iran, fall in the field of *A. sapidus*. By the way, it is to be noted that the Iranian populations of *A. amphibius* have been ascribed to a new species: *A. persicus* (Mahmoudi et al. 2019). These authors confirm the existence of 5 species for the genus *Arvicola*: *A. amphibius*, *A. italicus*, *A. monticola*, *A. persicus* and *A. sapidus*; considering in particular the wide distribution of *A. amphibius*, multidisciplinary investigations on the different populations will certainly prove to be interesting.

On the basis of the performed measurements, the two-way analysis of variance (Table 7) and the one-way analysis of variance (Table 8) show that the taxon is significant for all measures with the exception of UDL, the age for the measures CBL, ICW, UDL, UMS, ML, HC, RZ, NL, CH, ZW and IC and the significant taxon-age interaction for the measures CBL, ICW, UDL, ML, HC, CH, ZW and IC. When the age effect is significant, the considered factor is greater in adults than in juveniles specimens with the exception of ICW and IC.

According to our results, *A. italicus* is very different from *A. amphibius* (14 variables over 17 significantly in sexually mature specimens) and *A. monticola* (14 variables over 17 significantly different in sexually mature specimens) and similar to *A. sapidus* (only

ML/HC ratio different in in sexually mature specimens), even if the scarce material of *A. sapidus* sometimes did not allow to highlight a significant difference when the means were notably different (upper diastema length, mandible height, cranial index).

Beside the morphological and morphometric analyses of skulls, it will be interesting and necessary in a future phase to perform morphometry of the first lower molar (cf. Paunescu & Brunet-Lecomte 2013).

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