C. R. Palevol 18 (2019) 13–23

Contents lists available at ScienceDirect

Comptes Rendus Palevol

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General Palaeontology, Systematics, and Evolution (Palaeoecology)

Palaeoenvironment and palaeoclimate in the western Liguria region (northwestern Italy) during the Last Glacial. The small mammal sequence of Riparo Mochi (Balzi Rossi, Ventimiglia)

Paléoenvironnement et paléoclimat en Ligurie occidentale (Nord-Ouest de l'Italie) au cours de la dernière période glaciaire. La séquence de petits mammifères du Riparo Mochi (Balzi Rossi, Vintimille)

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ARTICLE INFO

Article history:
Received 4 January 2018
Accepted after revision 29 April 2018
Available online 4 July 2018

Handled by Lars W. van den Hoek Ostende

Keywords:
Upper Pleistocene
Paleoclimatology
Late Glacial
Gravettian
Insectivores
Rodents

ABSTRACT

Riparo Mochi is considered a key site for the Middle–Upper Palaeolithic chrono-cultural sequence in the Mediterranean area. Climatic and environmental conditions have been reconstructed after the study of the small mammal assemblage by means of linear regression method and the Habitat Weighting method. The climate proxies for the late Mousterian and Proto-Aurignacian (cultural units I to G) indicate an environment with a relative high percentage of forest component during two cold and one relative warm oscillations. Open environments with low temperatures are registered for the Gravettian (cultural Unit D) allowing a possible relation to the Heinrich 3 Event. The final Gravettian (cultural Unit C) shows a relative warm peak, tentatively related to Greenland Interstadial 2. The late Epigravettian (cultural Unit A) is characterized by a high percentage of forest-related environment suggesting that this horizon formed during the Bølling–Allerød Interstadial. Finally, the Riparo Mochi sequence contributes to reconstruct the processes of faunal changes along the northern Tyrrhenian coast in a period of climatic instability, especially during the end of Marine Isotope Stage 3 when foraging groups adopted different mobility strategies between southern France and the Italian peninsula.

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Mots clés :
Pléistocène supérieur
Paléoclimatologie

RÉSUMÉ

Le Riparo Mochi est un site clé pour la séquence chrono-culturelle Paléolithique moyen–supérieur de la région méditerranéenne. Les conditions climatiques et environnementales ont été reconstruites à partir de l'étude de l'assemblage de petits mammifères

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https://doi.org/10.1016/j.crpv.2018.04.007
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Dernier Glaciaire
Gravettien
Insectivores
Rongeurs

par les méthodes de moyennes de régression linéaire et *Habitat Weighting*. Les données climatiques pour le Moustérien final et le Proto-Aurignacien (unités culturelles I à G) indiquent un environnement composé, d'une part relativement importante de forêt au cours de deux oscillations froides et une oscillation relativement chaude. Un environnement ouvert avec des températures basses est enregistré pour le Gravettien (unité culturelle D), permettant une corrélation possible avec l'évènement Heinrich 3. Le Gravettien final (unité culturelle C) présente des pics chauds, pouvant être reliés au Greenland Interstadial 2. L'Épigravettien final (unité culturelle A) est caractérisé par une proportion importante d'environnement forestier, suggérant que cet horizon s'est formé pendant l'interglaciaire Bølling–Allerød. La séquence du Riparo Mochi contribue à la reconstruction des processus de changement faunique le long de la côte Nord-Tyrrhénienne pendant une période d'instabilité climatique, particulièrement à la fin du MIS 3, lorsque les groupes de chasseurs-cueilleurs adoptent différentes stratégies de mobilité entre le Sud de la France et la péninsule Italienne.
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1. Introduction

The environment and climate reconstructions of MIS 3 and 2 of central and southern Europe have been widely discussed (Barron and Pollard, 2002; Monegato et al., 2011; Pini et al., 2010a among others). Most research focuses on the possible climatic causes that led to the Neanderthal extinction and that could have driven the diffusion of Anatomically Modern Humans in Europe (e.g., Fedele et al., 2002; Higham et al., 2009; López-García et al., 2015).

Thirteen continuous and repeated climate cycles, such as Dansgaard–Oeschger (DO = GI) and Heinrich Events (H), have been recognized between 50,000 and 20,000 years BP in Greenland and North Atlantic cores (Andersen et al., 2006; Bond et al., 1993; Dansgaard et al., 1993; Rasmussen et al., 2014, among others). By contrast, continental records supporting these events are rare and usually incomplete, mainly because of hiatuses in sedimentation and/or poor dating (Spötl and Mangini, 2002). Nevertheless, several studies allowed us to correlate the MIS 3 climate cycles to changes in the small mammal communities found throughout the stratigraphic sequences, especially in the Mediterranean area (e.g., Berto et al., 2017a; Burjachs et al., 2012; López-García et al., 2012, 2014b, 2015; Royer et al., 2013) contributing to reconstruct the climate conditions in which prehistoric hunter-gatherers lived.

In this context, little is known about small mammal variations in northwestern Italy during MIS 3 and 2, especially in the coastal region (Berto, 2013). This area has been recently recognized as key to better understand the land use strategies of the last Neanderthals as well as the diffusion of the Upper Palaeolithic technocomplexes such as the Protoaurignacian, Aurignacian, and Gravettian (Grimaldi and Santaniello, 2014; Grimaldi et al., 2014, Santaniello, 2016). The northern Tyrrhenian coast, the so-called Liguro-Provençal Arc (Fig. 1a), forms a narrow littoral corridor, 400 km long and a few kilometres wide, delimited by the Apennines and the western Alps to the north, and the Tyrrhenian Sea to the south, further linking central Tyrrhenian Italy to the Rhône Valley in France. During the MIS 3, the landscape of the Liguro-Provençal Arc was not very different from today's (Arobba and Caramiello, 2009; Pons-Branchu et al., 2010; Watts et al., 2000). This region was a narrow corridor even during glacial time according to the bathymetry of the sea bottom (IBCM, 2014). Consequently, from an archaeological perspective, the Liguro-Provençal Arc should have been a natural axis channelling the exchange of both humans and animals between central Italy and southern France (Porraz et al., 2010).

Here, we present for the first time a study of the entire collection of small mammals (insectivores and rodents) from the Riparo Mochi site (Balzi Rossi, Ventimiglia, Italy). This site holds one of the most important sections in the Tyrrhenian area, spanning from Mousterian to Epigravettian, and it is considered a key site for the investigations on the Middle-Upper Palaeolithic boundary (Douka et al., 2012; Higham et al., 2014). This paper aims to reconstruct the local environment and climate changes based on the small mammals. The reconstruction will be discussed taking in account other northern Italy small mammal sequences – such as Grotta del Broion (Colamussi, 2002) and Grotta di Fumane (López-García et al., 2015) – as well as pollen archives from southern France and northern Italy with their correlation to Oxygen Isotope records.

2. Riparo Mochi

Riparo Mochi (Mochi rock shelter) is a broad, shallow rock shelter situated in the Balzi Rossi archaeological complex, in western Liguria on the border between Italy and France (43°47′3.66″N, 7°32′4.18″E, 30 m a.s.l.). It is one of several prehistoric sites, also known as "Grimaldi caves" (de Villeneuve et al., 1919) that provided archaeological deposits ranging from the early Middle to the final Upper Palaeolithic (Fig. 1a).

The site was discovered in 1938 by A.C. Blanc and L. Cardini of the Italian Institute of Human Palaeontology (IsIPU). They performed first a small-scale testing over three trenches (A, B, C) (Blanc, 1938); trench A, later called "Central Trench", was enlarged and excavated systematically in 1941, 1942 and 1949. In 1959, another excavation carried out by Cardini yielded the Upper Palaeolithic layers located at the eastern and western side of the Central Trench. For nearly four decades the site was abandoned, but from 1995 to 2005, A. Bietti (La Sapienza University and

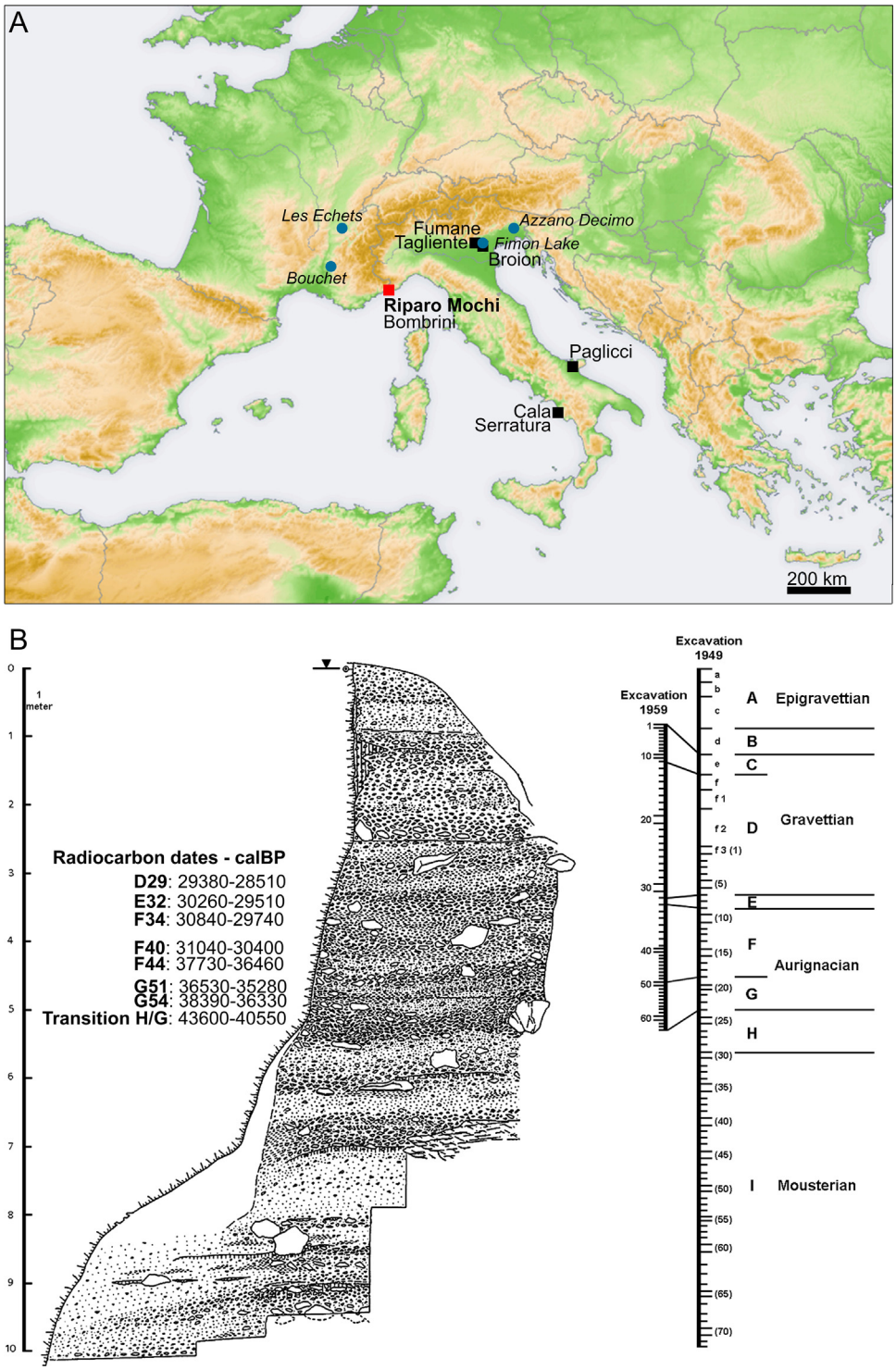

Fig. 1. A: Location of Riparo Mochi (red square); location of the most complete Italian Peninsula small mammal sequences (black squares); location of cited pollen records (blue dots). B: Riparo Mochi stratigraphy and selected radiocarbon dates cal BP (original drawing from Segre and modified from Blanc, 1954; for a complete framework about radiocarbon dates see Douka et al., 2012).

Fig. 1. Localisation du Riparo Mochi (carré rouge) ; localisation des séquences de petits mammifères les plus complètes de la péninsule Italienne (carrés noirs) ; localisation des données palynologiques citées (points bleus). B : Stratigraphie du Riparo Mochi (dessin original de Segre modifié par Blanc, 1954 ; Douka et al., 2012).

IIPU) resumed the excavations. Since 2007, the University of Trento, in collaboration with the former Soprintendenza Archeologica della Liguria started new research on this site, which is still ongoing. Thanks to this project, new radiocarbon dates of the lower part of the Upper Palaeolithic sequence have been published (Douka et al., 2012). Based on this evidence, the bottom of the cultural Unit G (Protoaurignacian) of Riparo Mochi, dating to around 37–36.5 ka BP, is the oldest directly-dated Upper Palaeolithic assemblage in Italy.

The chronocultural sequence, approximately 10 m deep, consists of nine units, mainly inferred in retrospect upon the characteristics of the embedded cultural remains (Grimaldi and Santaniello, 2014; Grimaldi et al., 2014; Laplace, 1977; Tomasso et al., 2014 among others), and named A to I, from top to bottom (Fig. 1b). Each cultural unit was excavated in 10 to 5 cm spits. Geoarchaeological observations on the upper 5.5 m of the sequence (Unit C–H) allow us to subdivide it into 3 facies. The first (Facies 1) consists of thick layers composed of limestone rubble in a sandy silty loam matrix; the second (Facies 2) is composed of silty clay loam units with hearts interbedded between them (Facies 3) (Douka et al., 2012). The lithological characteristics of the sequence in association with the site chronology, already described in Douka et al. (2012), show that the sequence was deposited mainly between MIS 3 and 2. Sixteen radiocarbon dates are available from the top of the cultural Unit I (Mousterian) to the bottom of cultural Unit D (Noaillian–Gravettian) providing a chronological range between 41,630–40,410 cal. BP and 29,380–28,510 years cal. BP. The upper part of the sequence has not been dated yet and the relative chronology is inferred by lithic evidence: the cultural Unit A yielded late Epigravettian tools while the cultural Unit C, covered by the sterile Unit B, has been attributed to Final Gravettian.

2.1. Previous paleoenvironment analyses

Several paleoenvironment analyses have been previously carried out on Riparo Mochi. These studies have focused on the pollen sequence (Renault-Miskovsky, 1972), large mammals (Alhaique, 2000; Arellano, 2009, 2004; Zeppieri, 2009, summarised in Tagliacozzo et al., 2012), and a sample of small mammals (Abbassi, 1999).

Twelve pollen samples collected from cultural Units G and F–E (1959 Cardini sequence, East sector) allowed us to reconstruct the environment of the region at the beginning of the Upper Palaeolithic (Renault-Miskovsky, 1972). The identified pollen essences came from plants currently living in the reliefs next to the site (starting from 600 m a.s.l.), such as conifers and deciduous trees, and from typical Mediterranean plants such as maritime pine and Oleaceae, nowadays present along the coast. Four environment oscillations were detected: a change from an open environment (Arboreal Pollen = 5%), with a regional cold and dry climate, to an increase of wooden areas (AP = 40–65%) with termophilic essences (Oleaceae 10–30%), suggesting a warmer phase related to the Arcy interstadial. Other two oscillations, testified only by two samples in Units F and E, show a cold and arid climate followed by a warmer phase.

The faunal evidence coming from Riparo Mochi was only partially studied by several authors. Arellano (2009) reported the large mammal species for the Mousterian sequence (cultural Unit I) without providing any detailed paleoenvironment and paleoclimatic reconstruction; however, three environmental changes were observed. In the lower spits, cervids are dominant and wild boar (*Sus scrofa*) is very abundant while the presence of roe deer suggests a relatively humid climate. This condition changes in the medium part of the unit where mammals such as *Rupicapra rupicapra* and *Capra ibex* increase and wild boar–among the forest ungulates, the most sensitive one to climatic changes–shows an abrupt decline, suggesting a colder phase in association with more arid conditions. In the upper part of the unit (i.e. final Mousterian), the forest fauna becomes dominant in association with *Dama dama* remains.

Alhaique (2000) analysed the faunal assemblage coming from the 1996–1996 Bietti's excavation (G to C Units). The Upper Palaeolithic sequence, although poor in material, provided some information. Red deer and roe deer are present in the whole sequence, but roe deer shows a higher frequency in unit G. *Marmota marmota* is also present in Units C and D; according to the author, the only individual found in Unit F might be intrusive.

A more detailed study of the large mammals evidence coming from Unit D (Gravettian, 1959 Cardini's excavation) is presented in Zeppieri (2009), later summarized in Tagliacozzo et al. (2012). The faunal remains from Unit D were divided into phases (from IV to I, from the bottom to top of the Unit) that have been associated with seasonality of several occupations; this subdivision should no longer be considered correct as it was established following the artificial stratigraphy defined by Cardini himself without any viable correlation with the geo-archaeological evidence (compare with Santaniello, 2016). Broadly speaking, at the base of the Unit D (Phase IV), the faunal spectrum indicates a wooded environment, with conifers and deciduous trees, characterized by a temperate to cool, climate. Such an ecosystem changed due to colder temperatures and a dry climate in the central phase of Unit D (Phase III and II), where the upper limit of the forest left space for alpine meadows. Finally, on top of Unit D (Phase I), the forest coverage was thicker, with temperate to cool and more humid climatic conditions. However, in all periods, there is a contemporaneous presence of temperate and forest fauna (*Cervus elaphus*, *Capreolus capreolus*, *Sus scrofa*) that probably lived in the immediate surroundings of the site, together with cold and open environment species (*Capra ibex*, *Rupicapra rupicapra*, *Marmota marmota*) which were present in mountain areas above the tree line.

A sample of small mammal fauna, collected by the "Laboratoire départemental de Préhistoire du Lazaret" in 1993 (Paunesco et al., 2010), was studied by Abbassi (1999). The sample was divided in cultural units following Blanc's (1954) stratigraphy with the only exception for the so called "Unit J", probably representing the base of the Unit I. The rodents identified along the sequence are *Marmota marmota*, *Eliomys quercinus*, *Muscardinus avellanarius*, *Microtus arvalis*, *Microtus* (*Terricola*) *multiplex*, *Chionomys nivalis*, *Arvicola amphibius*, *Arvicola sapidus*, *Clethrionomys*

glareolus, and *Apodemus flavicollis*, while the specimen identified as *Microtus* (*Terricola*) *savii* was later revised as *Microtus* (*Terricola*) *multiplex* (Paunesco et al., 2010). Abbassi (1999) suggested a Mediterranean climate, similar to present conditions, at the base of the sequence (possibly Unit "J"), which changes toward a colder and continental climate because of the presence of *Chionomys nivalis* and *Microtus* (*Terricola*) *multiplex*. The evidence found at the Middle–Upper Palaeolithic transition indicates an arid climate which becomes more continental in the upper Units G to C.

3. Material and methods

The small mammal remains from Riparo Mochi are represented by disarticulated bone fragments collected by water-screening using 1 mm mesh sieves during the Cardini (1938–1949, 1959) and Bietti (1995–2005) campaigns. The small mammal assemblage includes a total of 1244 remains, corresponding to a minimum number of 795 individuals (Table 1, Fig. 2). The specific attribution of this material was mainly based on the best diagnostic elements: mandible, maxilla and isolated teeth for rodents, mandible and maxilla for shrews, mandible, maxilla, isolated teeth and postcranial bones for Talpidae.

The taxonomic classification follows Wilson and Reeder (2005), except for *Clethrionomys glareolus* (for the priority over *Myodes*, see Tesakov et al., 2010). Data on the distribution and habitat of the species were taken from Amori et al. (2008), Boitani et al. (2003) and Mitchell-Jones et al. (1999).

We calculated the palaeodiversity using the Simpson index of Evenness = $1-\sum(p_i{}^2)$, where pi is the proportion of individuals in the ith species (Harper, 2005; Magurran, 2004). The evenness index is constrained between 0 and 1. The index has been calculated using PAST 3.04 avoiding redundant determinations (i.e. for *Microtus agrestis*, the individuals determined as *Microtus* cf. *agrestis* have not been included in the Simpson index calculation) (Hammer et al., 2001). A *Rattus* sp. first lower molar found on top of Unit D has been considered intrusive from Holocene sediments, thus this species has been not taken in account for paleoenvironment and paleoclimate reconstructions. Finally, despite the criticisms outlined above, a comparison with the seasonal phases described by Zeppieri in Tagliacozzo et al. (2012) is also discussed.

3.1. Paleoenvironment reconstruction

In order to reconstruct the paleoenvironment at Riparo Mochi, we used the Habitat Weighting method (Andrews, 2006; Evans et al., 1981), assigning each small mammal taxon to habitat(s) where it can be found today in Europe. To this purpose, habitats were divided up into six types (Cuenca-Bescós et al., 2010, 2009; López-García et al., 2014a): open land with either dry or wet meadows (OD and OH, respectively); woodland environments, divided into open woodland, woodland margins and forest patches (OW) and woodland and mature forest habitat (W); water, areas along streams, lakes and ponds (Wa); and habitats with a suitable rocky or stony substratum (R) (Table 1).

3.2. Climate reconstruction

Paleoclimatic data from Riparo Mochi have been calculated using the bioclimatic model described by Hernández Fernández (2001a, 2001b). First, the mammal assemblage was assigned to the climatic types described in Hernández Fernández (2001b) and in Walter (1970), following the values established in Hernández Fernández and Peláez-Campomanes (2005): IV–subtropical with winter rains and summer droughts; VI–typical temperate; VII–arid-

Table 1
Small mammal percentages of Minimum Number of Individuals (MNI) and small mammal distribution by habitat.
Tableau 1
Pourcentages de nombre minimum d'individus (NMI) de petits mammifères et distribution des petits mammifères par habitat.

	A	C	D I	D II	D III	D IV	E	F	G	H	I	*OD*	*OH*	*OW*	*W*	*R*	*Wa*
Arvicola amphibius	16.1	22.7	26.9	10.2	8.7	8.6	4.3	10.7	13	31.4	8.9						1
Chionomys nivalis		7.6	5.8	6.8	4.6	4.3		2.7	4.3	5.7	8.9					1	
Microtus arvalis	19.4	37.9	30.8	48.9	60	56.2	60.9	32	43.5	28.6	15.6	1					
Microtus agrestis	12.9			5.7	3.1	4.3					2.2		0.5	0.5			
Microtus cf. *agrestis*			1.9	1.1									0.5	0.5			
Microtus (*Terricola*) gr. *multiplex-subterraneus*	6.5	6.1	3.8	6.8	8.2	10.5	8.7	9.3	4.3	11.4	20		0.5	0.5			
Clethrionomys glareolus						0.6	4.3			2.9	15.6			0.25	0.75		
Apodemus sp.	16.1	6.1	5.8	4.5	1.5	3.1	13.0	18.7	8.7	5.7	11.1				1		
Apodemus sylvaticus		1.5	1.9		0.5			2.7			4.4				1		
Apodemus flavicollis	3.2	1.5		2.3	0.5	1.2		2.7	8.7	2.9					1		
Rattus sp.			1.9											-	-		
Eliomys quercinus	3.2	1.5				0.6		1.3			2.2				0.75	0.25	
Talpa sp.			1.9		1.5	0.6							0.5	0.5			
Talpa europaea	22.6	12.1	15.4	11.4	8.7	6.2	8.7	16	17.4	11.4	6.7		0.5	0.5			
Erinaceus europaeus			3.8	2.3		2.5		4			2.2			0.25	0.75		
Sorex gr. *araneus*					2.1	1.2					2.2		0.75	0.25			
Sorex sp.					0.5								0.75	0.25			
Neomys sp.		3.0											0.75				0.5
Total MNI	**31**	**66**	**52**	**88**	**195**	**162**	**23**	**75**	**23**	**35**	**45**						
Total NISP	**52**	**114**	**79**	**160**	**306**	**244**	**40**	**105**	**28**	**50**	**66**						

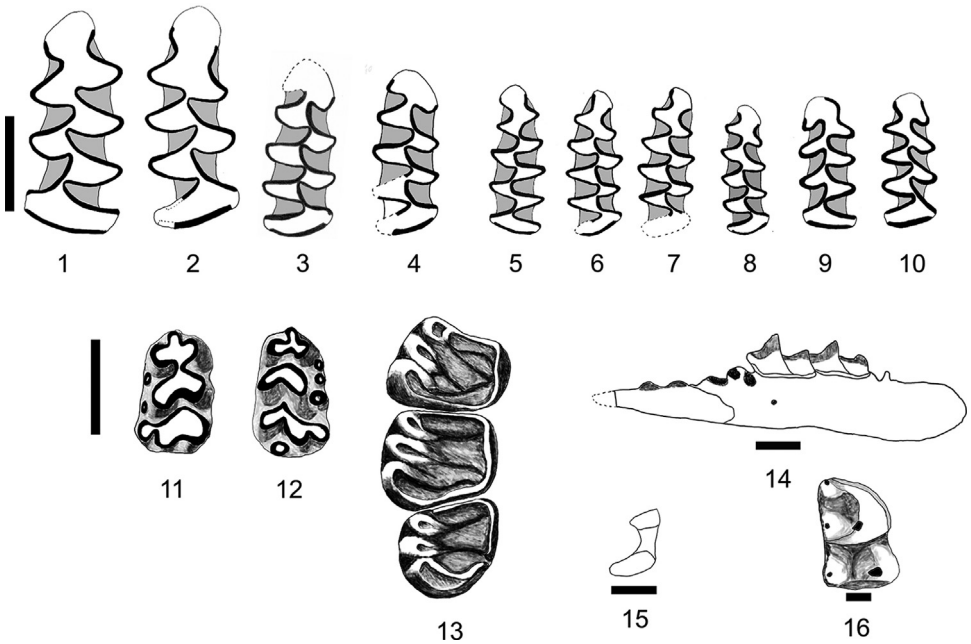

Fig. 2. Some identified small mammals from Riparo Mochi, all scales are 1 mm long. 1 and 2: *Arvicola amphibius*, left and right m1; 3 and 4: *Chionomys nivalis*, right m1; 5, 6, and 7: *Microtus arvalis*, one right m1 and two left m1; 8: *Microtus* (*Terricola*) gr. *multiplex-subterraneus*, right m1; 9 and 10: *Clethrionomys glareolus*, left and right m1; 11: *Apodemus sylvaticus*, left m1; 12: *Apodemus flavicollis*, right m1; 13: *Eliomys quercinus*, left m1, m2, and m3; 14: *Sorex* gr. *araneus*, left mandible; 15: *Neomys* sp., mandibular condyle; 16: *Erinaceus europaeus*, right m1.

Fig. 2. Exemples de petits mammifères identifiés au Riparo Mochi ; toutes les échelles sont de 1 mm de long. 1 et 2 : *Arvicola amphibius*, m1 gauche et droite ; 3 et 4 : *Chionomys nivalis*, m1 droite ; 5, 6 et 7 : *Microtus arvalis*, une m1 droite et deux m1 gauches ; 8 : *Microtus* (*Terricola*) gr. *multiplex-subterraneus*, m1 droite ; 9 et 10 : *Clethrionomys glareolus*, m1 gauche et droite ; 11 : *Apodemus sylvaticus*, m1 gauche ; 12 : *Apodemus flavicollis*, m1 droite ; 13 : *Eliomys quercinus*, m1, m2, m3 gauches ; 14 : *Sorex* gr. *araneus*, mandibule gauche ; 15 : *Neomys* sp., condyle mandibulaire ; 16 : *Erinaceus europaeus*, m1 droite.

temperate; VIII–cold-temperate (boreal); IX–polar. The faunal assemblage was analysed using the Climatic Restriction Index ($CRI_i = 1/n$, where n is the number of climatic zones inhabited by the species and i is the climatic zone where the species appears).

Afterwards, the Bioclimatic Component (BC) was calculated using the following formula: $BC_i = (\Sigma\ CRI_i) \times 100/S$, where S is the number of species by unit at Riparo Mochi. From the BC, climatic parameters were estimated with multiple linear regression method using the values given by Hernández Fernández and Peláez-Campomanes (2005). Mean Annual Temperatures (MAT), Mean Temperatures of the Coldest and Warmest month (MTC and MTW respectively) and Mean Annual Precipitation (MAP) were obtained. The data were compared with the present conditions registered at Sanremo meteorological station (Imperia, Liguria, 43°47'N, 7°46'E, 9 m a.s.l.), approximately 20 km east from the site. The current data are: MAT = 16.4 °C, MTW = 23.5 °C, MTC = 9.5 °C and MAP = 773 mm.

4. Results and discussion

4.1. The Riparo Mochi sequence

The small mammal assemblage of Riparo Mochi is characterized by high percentage of open environment-related arvicolids such as *Microtus arvalis* and *Microtus* (*Terricola*) gr. *multiplex-subterraneus*. Species that live in forest or in forest margins (*Apodemus* gr. *sylvaticus-flavicollis*, *Clethrionomys glareolus*) reach relative high percentages only in Unit I, F, and A.

Arvicola amphibius, a species that in the Italian peninsula lives near water streams, lakes and ponds, is present throughout the sequence. All *Arvicola* specimens have positive or *Microtus*-type enamel (Fig. 2, number 1 and 2). Thus, the presence of *Arvicola sapidus*, a species characterized by a negative or *Mimomys*-type enamel, signalled by Abbassi (1999) at Riparo Mochi is not confirmed.

The BC_i values (Table 2), related only to presence/absence of species, are dominated by component VI because most the rodents found at Riparo Mochi currently live in temperate climate areas (Mitchell-Jones et al., 1999). Nevertheless, the Habitat Weighting variations, connected to the abundant or poor presence of insectivores and rodents in the assemblage, indicate that several environment changes happened during the formation of the sequence.

As the Units from I to E (Table 1) are characterized by a low MNI, conclusions on environment and climate changes during the transition from the Mousterian to the Aurignacian must be considered with caution.

In Unit I (NMI = 45), the biodiversity is high and equally distributed (Simpson index = 0.865; Table 2) and the presence of forest-related species is relatively high (OW = 22.68%; W = 30.56). The precipitation value is the lowest of the entire sequence (MAP = 872 mm), while temperature proxies indicate the presence of very cold

Table 2
Biodiversity, Climate and Landscape values. Percentage representation of small mammal taxa associated with open dry meadows (OD), open humid meadows (OH), open woodland environments (OW), woodland environments (W), rocky environments (R) and landscapes constituted by river, lakes and ponds (Wa); bioclimatic components (BC_i); temperature and precipitation reconstruction for Riparo Mochi sequence: MAT: Mean Annual Temperature, MTW: Mean Temperature of the Warmest month, MTC: Mean Temperature of the Coldest month, MAP: Mean Annual Precipitation. Number of taxa in each layer; values obtained for evenness: Simpson diversity index = $1 - \sum(p_i{}^2)$.
Tableau 2
Valeurs de biodiversité, climat et paysage. Représentation des pourcentages des taxons de petits mammifères associés à une prairie sèche ouverte (OD), une prairie humide ouverte (OH), un environnement boisé ouvert (OW), un environnement boisé (W), un environnement rocheux (R) et des paysages constitués de rivières, lacs et étangs (Wa) ; composants bioclimatiques (BC_i) ; reconstruction des températures et des précipitations de la séquence du Riparo Mochi : MAT, moyenne des températures annuelles, MTW, moyenne des températures du mois le plus chaud, MTC, moyenne des températures du mois le plus froid, MAP, moyenne des précipitations annuelles. Nombre de taxons pour chaque niveau ; valeurs obtenues pour la régularité des espèces : indice de diversité de Simpson = $1-\sum(p_i{}^2)$.

	% Habitat Weighting						BCi					Climate records				Biodiversity	
	OD	OH	OW	W	R	Wa	IV	VI	VII	VIII	IX	MAT	MTW	MTC	MAP	N taxa	1-D
A	19.35	20.97	20.97	21.77	0.81	16.13	12.50	54.17	4.17	10.71	0.00	13.2	19.0	8.4	1822	7	0.826
C	37.88	11.36	12.12	10.23	7.95	24.24	25.00	75.00	4.17	7.14	3.13	9.7	16.6	4.3	1345	8	0.771
D I	30.77	10.58	15.38	10.58	5.77	26.92	16.67	58.33	4.17	14.29	3.13	9.7	17.4	3.1	1465	8	0.780
D II	48.86	12.50	12.50	8.52	6.82	10.23	8.33	66.67	4.17	14.29	3.13	9.2	16.2	3.3	1695	8	0.714
D III	59.69	11.48	9.95	2.55	4.59	8.67	16.67	75.00	4.17	14.29	3.13	7.4	15.5	0.7	1381	8	0.598
D IV	56.17	11.42	10.65	7.10	4.48	8.64	16.67	83.33	4.17	21.43	3.13	3.4	13.7	-5.5	1102	11	0.651
E	60.87	8.70	18.48	16.30		4.35	4.17	45.83	4.17	10.71		15.0	19.7	11.0	2136	6	0.594
F	32.00	12.67	16.33	28.00	3.00	10.67	25.00	75.00	4.17	7.14	3.13	9.7	16.6	4.3	1345	8	0.792
G	43.48	10.87	19.57	17.39	4.35	13.04	8.33	58.33	4.17	7.14	3.13	13.2	18.0	9.6	1974	6	0.730
H	28.57	11.43	17.86	10.71	5.71	31.43	8.33	66.67	4.17	14.29	3.13	9.2	16.2	3.3	1695	7	0.782
I	15.56	16.11	22.78	30.56	9.44	8.89	25.00	75.00	4.17	21.43	3.13	3.9	14.9	-5.8	872	11	0.865

conditions (MAT = 3.9 °C). Such climate data are directly related to the high percentage of *Chionomys nivalis* (8.9%), the absence of forest species such as *Glis glis*, the low percentage of *Erinaceus europaeus*, and the high percentage of *Microtus arvalis* and *Microtus* (*Terricola*) gr. *multiplex-subterraneus*. Thus, it is possible to suggest the presence of an environment characterized by tree patches in an open and rocky area rather than a dense forested landscape.

The cold climate evolves to slightly warmer conditions through the sequence (Units H and G) reflected in a more open environment. The rise in temperature and open environment may be related to a different precipitation distribution that caused the loss of biodiversity and the forest environment reduction (Fig. 3).

Unit F (early Aurignacian) is the most reliable layer of this portion of the sequence (NMI = 75): it is dominated by *Microtus arvalis* (32%), but the genus *Apodemus* is well represented (*Apodemus* sp. and *Apodemus* gr. *sylvaticus-flavicollis* > 20%). The environment was probably made up of sparse wooden areas without bush and open meadows. This reconstruction can be implemented thanks to the palynological analyses carried out at the Riparo Bombrini, a rock shelter located few tens of meters eastward to Riparo Mochi, which yielded layers related to Middle-Upper Palaeolithic transition. The authors suggested the presence of space pinewood, mixed oakwood, and thermophilous taxa related to the coastal area in the final Mousterian layers; warmer temperatures with a reduced tree covering were recorded during the deposition of the early Upper Palaeolithic layers (Arobba and Caramiello, 2009).

The loss of equality in the small mammal assemblage distribution continues in Unit E of Riparo Mochi. Here, few small mammals have been recovered (NMI = 23) to reach the lowest values in Unit D. Phases D IV, III, and II are dominated by one species, *Microtus arvalis*; the biodiversity is relatively low when compared to the lowermost phase (1-D values from 0.598 to 0.714). The forest components decrease in favour of the one indicative of more open environments due to a cold and dry climate. From phase IV to II, a slight climate improvement is registered; its peak is reached during a relative temperate cycle which characterizes the phase I (top of Unit D) as well as the Unit C, even if the general context is dominated by cold climate conditions. In these units, the arise of a water component represented mainly by *Arvicola amphibius* suggests the presence of a fluvial or a water-related environment, probably due to the presence of the San Luigi river, about 450 m to the west of the site.

After the thin and sterile Unit B, the Riparo Mochi sequence ends with the cultural Unit A (Epigravettian). This Unit also has a low NMI but the high percentage of forest-related indicators and the relative warm temperatures suggest that the unit formed in an environment similar to the present one.

4.2. Correlation between Riparo Mochi sequence and other climate proxies

The relatively high percentage of forest related species in Units I to F suggests that, in the period of time between DO (=GI) 12 and H 4 (following Douka et al., 2012), the western Liguria environment was conditioned by the Mediterranean Sea influence. This is also confirmed by pollen data indicating the presence of Mediterranean plants (Oleaceae) through the Riparo Mochi sequence (Renault-Miskovsky, 1972). In contrast, the percentage decrease of *Microtus* (*Terricola*) *multiplex-subterraneus* and *Clethrionomys glareolus* suggests an environment modification from a forest with shrubs and a well-formed substratum (Unit I, Mousterian) to an open forest (Unit F, early Aurignacian). The change is probably due to a climate deterioration related to a stadial episode of MIS 3. Unfortunately, it is not possible to argue

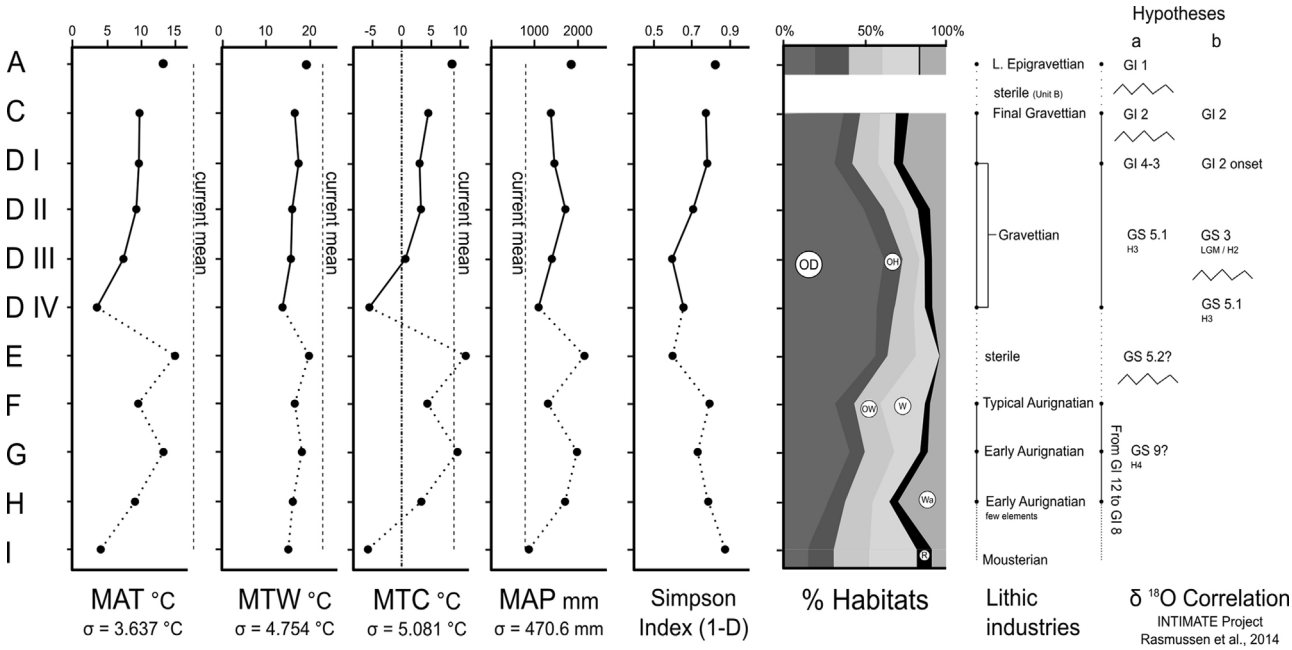

Fig. 3. Representation of the small mammal Simpson diversity index (1-D), the mean annual precipitation (MAP), the mean temperature of the coldest month (MTC), the mean annual temperature (MAT), the mean temperature of the warmest month (MTW) and the landscape percentages (OD: open meadows; OH: open humid meadows; W: woodlands; R: rocky areas; Wa: areas along streams, lakes and ponds). GI: Greenland Interstadial; GS: Greenland Stadial.
Fig. 3. Représentation de l'indice de diversité de Simpson des petits mammifères (1-D), moyenne des précipitations annuelles (MAP), moyenne des températures du mois le plus froid (MTC), moyenne annuelle des températures (MAT), moyenne des températures du mois le plus chaud (MTW) et pourcentages de paysage (OD : prairies ouvertes ; OH : prairies humides ouvertes ; W : bois ; R : zones rocheuses ; Wa : zones le long de ruisseaux, lacs et étangs). GI : Interstade groenlandais. GS : Stade groenlandais.

whether this change is related only to H 4 rather or any other stadials (GS 12, 11, 10, and 9).

Riparo Mochi Units from I to F can be compared to layers SU A5 + A6 to A1 of the Fumane Cave (Verona, Italy). There, a decrease in percentage of woodland coverage is registered and this reduction culminates in layers A3-A1 that are attributed to Heinrich Event 4 (López-García et al., 2015). Differences between the two sequences must be noticed: at the Riparo Mochi, the biodiversity is lower than in the Fumane cave and boreal/continental climate indicators, as well as eastern Europe species such as *Dinaromys bogdanovi*, *Microtus oeconomus*, *Sicista betulina*, and *Cricetus cricetus* are absent. The composition of the Riparo Mochi assemblage is better related to southwestern Italian peninsula coastal sites, at Grotta della Cala and Grotta della Serratura (Bambini, 1996; Bertolini et al., 1996), where such cold climate related species are absent, rather than to northern Italian Peninsula sites (Berto, 2013; Bon and Boscato, 1996; López-García et al., 2014a; Masini and Abbazzi, 1997).

Three short and not yet chronologically determined interstadials characterized by sparse tree cover are also found in two French site pollen records: Les Échets, zone G (Beaulieu and Reille, 2008) and Bouchet (Reille et al., 2000). Finally, the Riparo Mochi cultural Units I to F can be related to the palaeoenvironmental reconstructions suggested for Fimon Lake (FP 17a, 17b, and 17c) and for Azzano Decimo (AZ 65-67), in the southern Alps. The southern Alps pollen records show a thick tree coverage and, even during stadial periods because the environment was dominated by *Pinus* and *Betula* probably due to orographic precipitations (Pini et al., 2010b, 2009). Available dates (Douka et al., 2012) allow us to relate the base of Unit D of Riparo Mochi (Zeppieri's phase IV) to Heinrich Event 3. The effects of the cold and arid climate are clearly visible on the small mammal assemblage–especially when phases IV and III of Unit D are considered – and they can be related to Les Échets (zone O), Fimon Lake (FP 18), and Azzano Decimo (AZ 68).

The Unit D (phase III) temperature increase followed by an open environment decrease visible at the top of Unit D of Riparo Mochi can be related to episodes following the H3. No abrupt changes are visible in the transition from the top of Unit D to Unit C, although the latter is attributed to the final Gravettian technocomplex, chronologically related to Last Glacial Maximum (LGM) and DO 2 (Berto, 2013; Douka et al., 2012; Palma di Cesnola, 1993). No radiometric dates are available yet, but two hypotheses can be proposed assuming that the open environment decrease in Unit C is related to the DO 2: A) the upper part of Unit D can be related to DO 4-3, two cycles chronologically close and hardly distinguishable without radiometric datings in a continental sequence, a hiatus in sedimentation is also present between LGM and DO 2; B) the deposition of Unit D took place in period between H3 and LGM.

Italian small mammal sequences related to H3 and following DO cycles are very scarce; the climatic deterioration related to this event in northern Italy is visible only at Grotta del Broion (layers G2–F), where a decrease of forest related species is registered (Colamussi, 2002). In southern Italy, the forest indicators decrease at Grotta della Cala

(3m-1) (Bambini, 1996) and the increase in percentage of *Microtus arvalis* at Grotta Paglicci (22b to 21c) can be related to H3 (Berto et al., 2017a).

The late Epigravettian Unit A of Riparo Mochi is characterized by the high percentage of forest related species. The Unit probably accumulated after the turnover registered during the Late Glacial in the small mammal communities. In southwestern France, cold-climate species such as *Microtus oeconomus*, *Microtus gregalis* and *Spermophilus* sp. were replaced by forest-related species (Royer et al., 2016) while in the southern Alps, species related to cold-continental climates such as *Dinaromys bogdanovi*, *Microtus oeconomus* and *Cricetus cricetus* disappeared (i.e. at Riparo Tagliente, Berto et al., 2017b). Finally, in southern Italy the small mammal communities, dominated during the MIS 3 and 2 by *Microtus arvalis*, changed to forest related assemblages (dominated by *Glis glis*) or to a strictly Mediterranean-related community dominated by *Microtus* (*Terricola*) *savii* (Berto et al., 2017a; López-García et al., 2014a). The changes are related to Bølling–Allerød Interstadial afforestation registered also in pollen sequences (Berto et al., 2017b; Ravazzi et al., 2007).

5. Conclusions

The small mammal analysis from Riparo Mochi allows us to reconstruct the environment and its changes in the region surrounding the site from the final Middle Palaeolithic to the Upper Palaeolithic. The changes are due to D/O cycles and Heinrich Events registered during MIS 3 and 2 and detected in numerous climate proxies of European continental sequences.

Due to its particular position, the small mammal community of Riparo Mochi has been influenced by the Mediterranean climate and, even during the coldest stadial period of MIS 3, species related to boreal regions usually documented in northern Italy did not reach this area.

During the Middle to Upper Palaeolithic transition, two cold and one slightly warm oscillations were detected depicting a forest and bush reduction near the shelter. It was probably due to stadial moments not highlighted throughout the low small mammals MNI registered in the collection.

During the Gravettian, the environment changed from one dominated mainly by open grasslands, related to a cold and dry climate, to one characterized by open forests with an increase of water streams, the latter probably due to the flow rate of the near San Luigi river. The radiometric date at the base of Unit D and the presence of lithic tools related to final Gravettian in Unit C indicate that this portion of the sequence formed between H3 and D/O (GI) 2.

The small mammal assemblage of the uppermost Unit A, related to final Epigravettian, indicates the presence of a forested environment. This Unit probably formed after the faunal turnover registered in southern Europe during the Late Glacial.

The sequence of small mammal assemblages at Riparo Mochi fills a gap between southern Italy and southern France small mammal sequences, confirming the sequence as a reference one not only for the Middle to Upper Palaeolithic transition but also for the transition from MIS 3 and MIS 2.

Acknowledgements

The Dipartimento di Lettere e Filosofia, Università degli studi di Trento (Italia) partially supported this study. The former Soprintendenza per i Beni Archeologici della Liguria granted the permission for the study; in particular, we thank Dr. Angiolo Del Lucchese and Dr. Elisabetta Starnini. We are grateful to many people and friends who helped us during the fieldwork, especially to M. A. Segré and the staff of the Museo Preistorico dei Balzi Rossi. We want to thank the editorial secretary Fathia Lemhemdi and the reviewers Juan Manuel López-García and Lars van den Hoek Ostende for their comments that improved the final version of the manuscript. The authors also thank Benedetto Sala and Elisa Luzi for their useful suggestions and Julie Arnaud for the French spelling check. Finally, we are in debt with A. Segre who generously gave us direct information and original field documentation about the Riparo Mochi excavation.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.crpv.2018.04.007.

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