PALAEOENVIRONMENTAL CONSIDERATIONS
ON THE LATEST PLEISTOCENE AND HOLOCENE MICROMAMMALS
FROM THE GROTTA DEI PIPISTRELLI
(HYBLAEAN MOUNTAINS, SICILY, ITALY).

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ABSTRACT: The Eulipotyphla and Rodentia remains from the Grotta dei Pipistrelli in Sicily (Italy), a key region for the historical reconstruction of the Quaternary climates and environments of the central Mediterranean basin, are described and discussed. Three ^{14}C radiometric dating display that the fossil remains were accumulated during the Last Glacial Maximum (LGM) and in the middle Holocene. Taphonomic observations show that the small mammal remains probably come from *Asio otus* pellets. Both the micromammal assemblages are oligotypical and similar to each other. However, the relative abundance of *Apodemus sylvaticus* suggest temperate-warm and humid climatic conditions, in both LGM and middle Holocene. The frequency variations in the recognized taxa indicate that the palaeoenvironment was slightly more wooded in the LGM than during the middle Holocene.
These results complement previous studies and allow the outline of a composite landscape with wooded areas interrupted by open spaces (grassland, steppe), shrubland and rocky areas, where the water supply provided by Anapo River and its tributaries was enough to support a rich vegetation cover, particularly in the LGM.

Keywords: Quaternary, small mammals, central Mediterranean, Pantalica Nature Reserve, palaeoenvironment.

1. INTRODUCTION

Sicily is located in a key geographic position for understanding Quaternary climate and environmental changes in the central Mediterranean basin (Fig. 1A). Recent studies on the Quaternary vertebrate assemblages of Sicily allowed the identification of up to 7 Faunal Complexes (=FCs) (e.g., Bonfiglio et al., 2003; Masini et al., 2008; Petruso et al., 2008; Marra, 2013). Faunal changes reflected by FCs are primarily related to the alternation of isolation and land-connections of Sicily with the Italian peninsula. The FCs are connected to dispersal events, followed by isolation phases, which induced processes of endemism (e.g., the middle Pleistocene dwarf elephants and giant dormices; Bonfiglio et al., 2003; Masini et al., 2008; Petruso et al., 2008; Marra, 2013). The latest Pleistocene assemblages are represented by the Castello FC and include a scarcely diversified mammal fauna, without archaic endemites, similar to southern Italy one, and with *Homo sapiens* (see Bonfiglio et al., 2003; Masini et al., 2008; Petruso et al., 2011a; Marra, 2013). Although the Castello FC was correlated with the last Pleniglacial - Lateglacial period (Masini et al., 2008; Petruso et al., 2008, 2011a),

there is actually no faunal assemblages known from the last Pleniglacial, except for a few remains of *Equus hydruntinus* Regalia, 1907 from Grotta San Teodoro, dated 23-21 ka cal. BP (Catalano et al., 2020). In Sicily, palaeoclimate and palaeoenvironment of the last Pleniglacial, around the Last Glacial Maximum (=LGM; 20±2 ka cal. BP, see Antonioli & Vai, 2004; Masini et al., 2008), are known by the sediments, pollen and microcharcoal of Pergusa Lake (Zanchetta et al., 2007; Sadori et al., 2008).

From the Holocene of Sicily, the large mammals are well known (e.g., Tagliacozzo, 1993; Villari, 1995; Burgio et al., 2005), but only few studies exist on small mammals (e.g., Surdi, 2008; López-García et al., 2013). The Holocene environmental and climatic changes are known based mainly on several pollen and charcoal studies (Bertolani Marchetti et al., 1984; Sadori et al., 2008, 2013; Noti et al., 2009; Tinner et al., 2009; Calò et al., 2012; Forgia et al., 2013).

The micromammal assemblages from Grotta dei Pipistrelli (literally, Cave of the Bats), near Sortino (Syracuse, Sicily, Italy), offer the possibility to fill these gaps, at least partly. Between 2014 and 2018, numerous micromammal remains have been collected in the *talus*
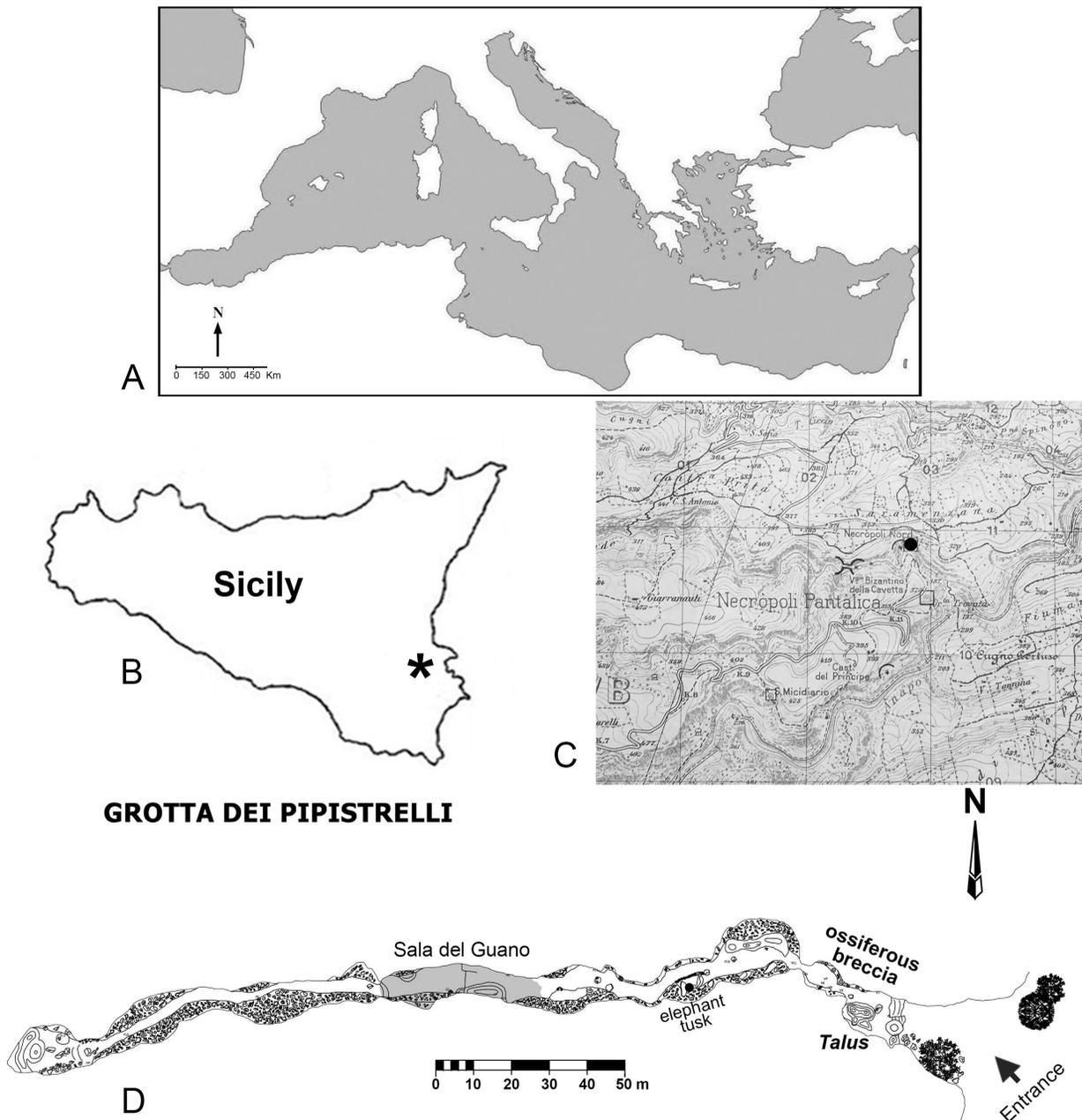
Fig. 1 - A) Mediterranean basin; B) Location of Grotta dei Pipistrelli near Sortino (Syracuse, Sicily, Italy); C) map of the Natural Reserve "Pantalica, Valle dell'Anapo e Torrente Cava Grande" area (from Istituto Geografico Militare, ed. 4 - 1968, Map of Italy at the scale 1:25000, Sheet 274, III, N.O., Sortino, redrawn and modified); black circle: Grotta dei Pipistrelli; D) plan of the cave.

area of this cave (Spena et al., 2017; Salari et al., 2019). The now investigated non-volant micromammal remains belong to Eulipotyphla, *Crocidura sicula* Miller, 1900, and to two Rodentia taxa, *Microtus savii* (De Sélys-Longchamps, 1838) group and *Apodemus sylvaticus* (Linnaeus, 1758).

According to three ^{14}C dating, the micromammal remains were accumulated during the Marine Isotope Stage (=MIS) 2, in the LGM, and in two events of middle Holocene referred to the Atlantic chronozone, Neolithic cultural phase (Salari et al., 2019).

Spena et al. (2017) reported a preliminary list of volant and non-volant small mammal fossils collected from 2014 to 2016. Salari et al. (2019) described the bat remains collected from 2014 to 2018 and discussed some chronological and palaeoecological implications. Nine taxa of Chiroptera have been identified: *Rhinolophus ferrumequinum* (Schreber, 1774), *R. euryale* Blasius, 1853, *R. mehelyi* Matschie, 1901, *Myotis myotis* (Borkhausen, 1797), *M. blythii* (Tomes, 1857), *M. capaccinii* (Bonaparte, 1837), *Myotis* cf. *M. mystacinus* (Kuhl, 1817), *Plecotus* cf. *P. auritus* (Linnaeus, 1758) and *Min-*

iopterus schreibersii (Kuhl, 1819).

The aim of this work on the fossil assemblages from Grotta dei Pipistrelli is to describe the non-volant micromammal remains and discuss the palaeoenvironmental reconstructions, comparing them with other Sicilian and southern Tyrrhenian Sea area fossil assemblages.

2. THE CAVE

Grotta dei Pipistrelli is located on the eastern side of the Hyblaean Mountains, in the Nature Reserve "Pantalica, Valle dell'Anapo e Torrente Cava Grande" (South-East Sicily; Figs. 1B-C; henceforth Pantalica Nature Reserve).

The area is characterized by a natural plateau, deeply engraved by the Anapo River and the Calcinara stream. Pantalica Nature Reserve (over 37 kmq) has been awarded in 2005 as UNESCO World Heritage Site for its history, archaeology, speleology and landscape (UNESCO, 1992-2019). It consists of various natural and semi-natural environments (riparian forest, woodland, shrubland, grassland, steppe) along with cultivated land (Minissale et al., 2007; AA.VV., 2009), which are essential habitats for many invertebrate and vertebrate communities.

As described in detail by Spena et al. (2013, 2017), Grotta dei Pipistrelli opens on a rocky wall overhanging the Calcinara stream, about 10 m from the left bank of the watercourse, in the Miocene "Calcari di Siracusa" formation. The karst cavity has a sub-horizontal development with a 7.3% West-East average slope and it has been explored for about 260 m (Fig. 1D): between the entrance of the cave, at 234 m above sea level (=a.s.l.), and the ending point (253 m a.s.l.). At the entrance, the cave has a large opening that quickly constricts into a funnel that enters into a first room. A gallery links the room to a large hall called "Sala del Guano", with a 15 m high vault consisting of three domes, which currently hosts huge bat colonies. The karst cavity continues with a series of galleries and small dome halls and it is then interrupted in a large terminal hall, where it ends in a duct enclosed by a thick layer of coarse detritus.

The cave hosts very large colonies of Chiroptera and it represents the biggest nursery roost of the region (Spena et al., 2013; Ferrante et al., 2018). From 2012 to date, Grotta dei Pipistrelli is the only systematically monitored bat cave in Sicily (Spena et al., 2013, 2017; Ferrante et al., 2018).

Several ossiferous breccia containing many small vertebrate remains (birds, insectivores, rodents and mostly bats) have been observed on the right wall of the *talus* close to the entrance since 1996. The terrain close to the right wall contains many fossils of small vertebrates and some bone remains of large mammals, too. Sediments of a gallery yelded a portion of elephant tusk, attributable to *Palaeoloxodon mnaidriensis* (Adams, 1874). In the *talus* close to the entrance, ossiferous breccia are spread on the surface of the right wall, from a couple of decimeters above the walking surface up to about 2 meters in height. In the ground near the right wall, the bone remains below the walking surface were found up to a few decimetres of depth. The walking surface does not contain fossil remains; the soil over 30/40 cm deep is sterile. Between 2014 and 2018, several campaigns of fossil remains collection in three closely associated areas of the *talus* were conducted. Samples were collected on the right wall, from the soil at the base of the same wall, and from the ground on a rocky ledge with guano at about 40 cm over the aforementioned soil.

Three ^{14}C dating have been carried out on micromammal bones by the Centre for Applied Physics, Dating and Diagnostics of Salento University in Lecce (Italy) and provided the following datings: 18,062±120 years BP (20,305-19,600 cal. BC) for the ossiferous breccia on the right wall, 6,472±45 years BP (5,513-5,339 cal. BC) for the bone remains collected in the soil at the base of the right wall, and 6,242±45 years BP (5,314-5,060 cal. BC) for the bone remains collected on the rocky ledge with guano (Salari et al., 2019).

3. MATERIALS AND METHODS

The sampling area, i.e. the right wall of the *talus* and the soil close to it, was associated with an assigned baseline and subdivided into 25 sections of 1 m wide, in order to relate each sample of soil and breccia with its position along the wall and its depth. Each sample was then assigned a progressive number and recorded with its section coordinates and depth. The samples were collected from three closely associated areas: on the surface of the right wall (about 9 m in length and 0.24/2.00 m in heigth; sections from 4-5 to 12-13), from the soil at the base of the same wall (between 2/3 and 30/40 cm of depth from the walking surface, for 6 m in length and 40/60 cm in wide; sections from 8-9 to 13-14) and from a rocky ledge with guano (just over a square meter between 0 and 4/5 cm in depth, sections 11-12 and 15-16).

The 12 calcareous breccia samples were dissolved in acetic acid, then filtered, using sieves of 1.60 and 0.63 mm mesh size and neutralized in water in order to stop further dissolving. The 13 soil samples (9 at the base of the right wall and 4 collected on the rocky ledge with guano) were screen washed in the laboratory and then dried. In the rocky ledge with guano, only bat remains were found.

The micromammal remains were compared with osteological material, both fossil and recent, from the Department of Sciences of "Roma Tre" University and in the Department of Earth Sciences of "Sapienza" Rome University. Morphological and morphometric investigations follow Repenning (1967), Niethammer & Krapp (1978), Nappi (2001), Amori et al. (2008) and Ronninger (2009). The analyses were carried out with a Nikon SMZ -U stereoscopic microscope in the Department of Sciences of "Roma Tre" University; measurements and pictures were taken with a Leika DFC290 system using the Leica Application Suite software.

Taphonomic observations were conducted following the methodologies of Andrews (1990) and Fernández-Jalvo et al. (2016), in order to investigate the possible agents responsible for the accumulation of the fossil remains.

For the taphonomic remarks and taxonomic identi-

fications, the analyses were focused on cranial elements (cranium, mandible, isolated teeth), and on humeri and femora. Dental terminology is: I: upper incisors; C: upper canine; P: upper premolars; M: upper molars; lower teeth are denoted by lowercase letters.

For each taxon, both the number of identified specimens (NISP) and the minimum number of individuals (MNI) is provided. The MNI was calculated based on the most frequently represented cranial element, with distinction of right and left body side; this result was integrated with the analysis of the age and the dimensional characters of other skeletal elements.

The environmental reconstructions, based on the ecology and geographical distribution of the corresponding current taxa (Niethammer & Krapp, 1978; AA.VV., 2008; Amori et al., 2008), include Chiroptera (Lanza & Agnelli, 2002; Agnelli et al., 2008), although this group was focus of other paper (Salari et al., 2019).

The authors (particularly JDM, RG and MTS) collected the analysed material. The fossil remains are currently deposited in the Department of Biological, Geological and Environmental Sciences of Catania University. The final collocation and cataloguing will be decided in agreement with the direction of Pantalica

Nature Reserve. Therefore, the inventory numbers of the samples given in this paper are provisional.

4. SYSTEMATIC NOTES

Order Eulipotyphla Waddell, Okada & Hasegawa, 1999
Family Soricidae Fisher, 1817
Genus Crocidurinae Wagler, 1832
Crocidura Wagler, 1832
Crocidura sicula Miller, 1900

Material: one splanchnocranium (Figs. 2A-B) and 2 mandibles of which one sub-entire from the late Pleistocene breccia; 2 fragmented mandibles from the Holocene soil.

Description and remarks: The splanchnocranium has the typical morphology of the genus *Crocidura*, in particular for the unpigmented teeth and for the presence of three pairs of upper unicuspid teeth, the first of which is larger than the equally-sized second and third ones (Repenning, 1967; Aloise et al., 2008). Furthermore, the P4 shows an angular and squared parastyle, and the dorsal edge of the cingulum is undulated, not straight. These features allow to attribute the above
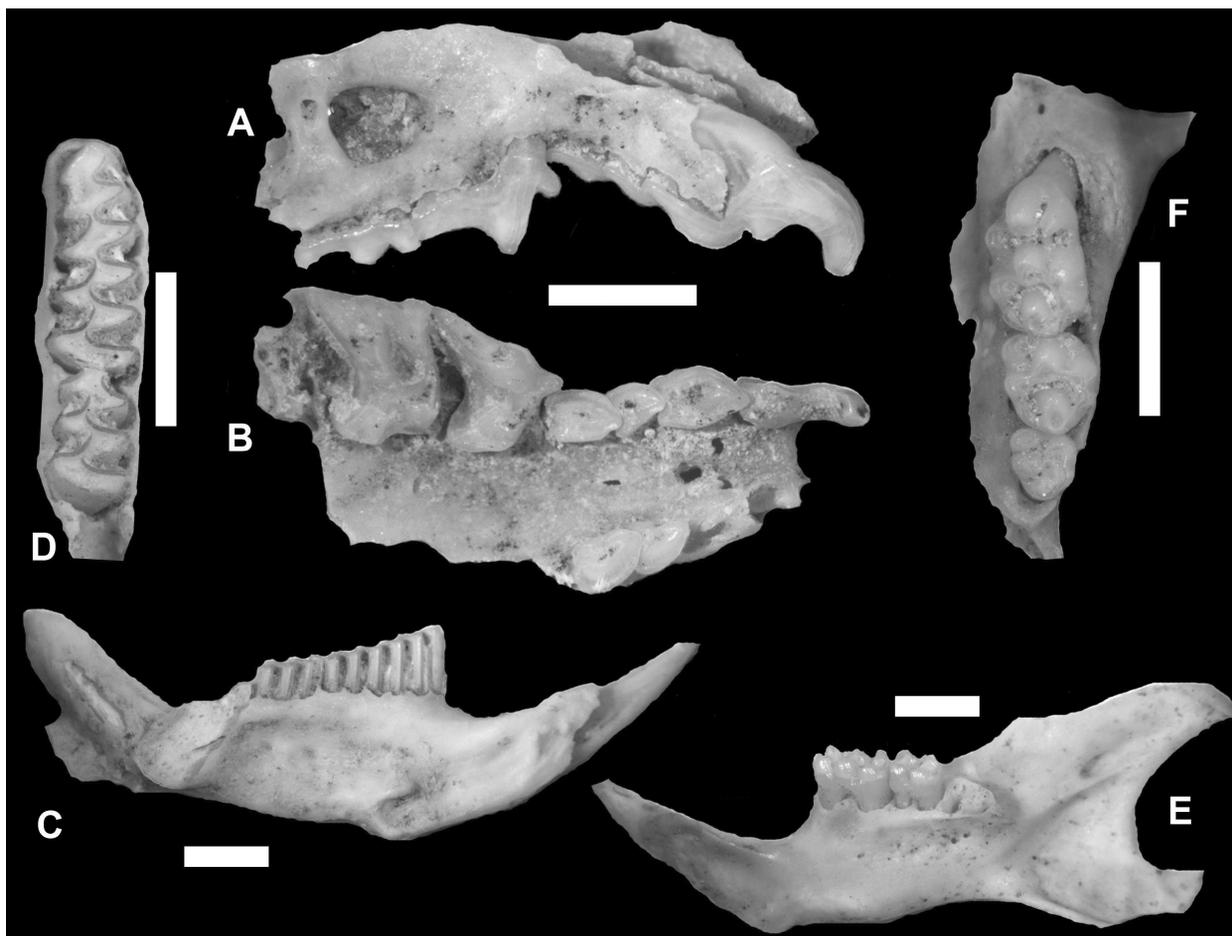

Fig. 2 - Grotta dei Pipistrelli (Sicily, Italy): *Crocidura sicula*, splanchnocranium (C4S5-6): A) labial view, B) occlusal view; *Microtus savii* group, left mandible (C5S5-5): C) lingual view; D) m1 and m2 in occlusal view; *Apodemus sylvaticus*: E) right mandible (C5S10-11) in lingual view; F) left maxilla fragment (C25S5-6) in occlusal view. Scale bars: 2 mm.

specimen to *C. sicula*, the Sicilian shrew, and to exclude other extant (Contoli, 2008) and extinct (Kotsakis, 1986, 2008) Italian species of the genus. As for the mandible, the shape of this skeletal element and of the lower teeth of the Sicilian shrew and of the Etruscan pygmy shrew, *Suncus etruscus* (Savi, 1822), are very similar. However, both the sizes (length of cheekteeth: 5.94 mm; length m1-m3: 3.87-3.96 mm) and biochronological reasons (*S. etruscus* reaches Sicily only in the late Holocene; Petruso et al., 2011a) exclude the occurrence of the Etruscan pygmy shrew in the Grotta dei Pipistrelli assemblages.

C. sicula occurs in Sicily since the San Teodoro FC (recorded as *Crocidura* cf. *C. sicula*, see Bonfiglio et al., 2003; Masini et al., 2008; Petruso et al., 2011a; Marra, 2013). Remains referable to *C. sicula* are recorded in some Lateglacial and Holocene sites of Sicily (Tagliacozzo, 1993; Burgio et al., 2005; Surdi, 2008; López-García et al., 2013).

The Sicilian shrew is a Mediterranean endemic species limited to the Sicilian and Maltese archipelagos (Sarà, 2008a). It is currently commonly widespread up to 1600 m a.s.l., both in woodland and less arid scrubland and in environments with herbaceous and shrubby vegetation (Cagnin & Grasso, 1999; Zanca & Sarà, 2008). It is also recorded in the Hyblaean Mountains (Zanca & Sarà, 2008; Aprile et al., 2010).

Order Rodentia Bowdich, 1821
Family Cricetidae Fischer, 1817
Subfamily Arvicolinae Gray, 1821
Genus *Microtus* Schrank, 1798
Subgenus *Terricola* Fatio, 1867
Microtus (Terricola) savii (De Sélys-Longchamps, 1838)

Material: 1 splanchnocranium, 2 maxillaries, 6 mandible fragments (Fig. 2C-D), 6 M1, 7 M2, 8 M3, 14 m1, 9 m2, 7 m3, 1 humerus and 1 femur from the late Pleistocene breccia; 3 splanchnocrania, 21 mostly fragmented mandibles, 1 M1, 5 M2, 8 M3, 24 m1, 15 m2, 11 m3 and 1 humerus from Holocene soil.

Description and remarks: The morphology of the m1, with seven triangles and the not triangular-shaped anterior loop, is typical of the *Microtus* genus (Amori & Capizzi, 2008). The anteroconid complex of this tooth shows broadly confluent T4 and T5 lobes, forming the so-called pitymyan rhombus, peculiar of the *Terricola* subgenus (Chaline et al., 1988; Nappi & Contoli, 2008). Furthermore, the M3 is of simplex type, the anterior loop of m1 is wide, extensive and few constricted, and the anteroconid complex is very short, squat and asymmetric. These features allow to refer the above specimens to *M. savii* group (Curcio et al., 2005; Contoli et al., 2008; Piras et al., 2010; Locatelli et al., 2011; Petruso et al., 2011b).

According to recent biomolecular studies, the extant Savi's pine vole of Sicily should be elevated to the rank of full species, *Microtus nebrodensis* (Minà-Palumbo, 1868) (Bezerra et al., 2016; Amori & Castiglia, 2018). Although these biomolecular works have estimated the divergence between *M. savii* and *M. nebrodensis* at about 0.6-1.0 Ma (latest early Pleistocene - middle part of the middle Pleistocene), the first occurrence of

fossil Arvicolinae teeth with characters similar to those of the extant *M. (T.) savii* are known from deposits dating back to the middle-late part of the middle Pleistocene (Kotsakis, 2008; Kotsakis et al., 2020). Therefore, at moment it is preferable to use the taxon "*Microtus savii* group", also pending solid morphometric data to discriminate between the two species and in agreement with the paleontological works that identify the late Pleistocene and Holocene Sicilian remains of Arvicolinae of subgenus *Terricola* as *M. savii* group.

Remains attributed to *M. savii* group occur in Sicily since the San Teodoro FC (second, but not terminal, part of the late Pleistocene) (Bonfiglio et al., 2003; Masini et al., 2008; Petruso et al., 2011a; Marra, 2013) and are recorded in several Lateglacial and Holocene sites (Tagliacozzo, 1993; Burgio et al., 2005; Martini et al., 2007; Surdi, 2008; López-García et al., 2013).

Today, the arvicoline of the *M. savii* group are restricted mainly to the Italian Peninsula, but are also found in South Switzerland and South-East France (Contoli et al., 2008), preferring open environments, such as grasslands, uncultivated and cultivated areas, and avoiding dense woodlands (Contoli et al., 2008; Capizzi, 2013). In Sicily, the Savi's pine vole, or better *M. nebrodensis*, is distributed up to 1800 m a.s.l., but prefer hilly areas and plains, particularly in the open and temperate environments, grassland and steppes, avoiding too hard, arid and stony soils and dense woods with rich undergrowth (Cagnin & Grasso, 1999; Sarà, 2008b). In the Hyblaean Mountains, it is recorded in the southern side (Siracusa, 1997), while in the central and eastern areas seems to be absent (Sarà, 2008b). However, it was recently found in some localities of the eastern side (G. Di Natale and M. Nanzarelli, *in litteris*), also within the boundaries of the Pantalica Nature Reserve (unpublished data by MTS and RG).

Family Muridae Illiger, 1811
Subfamily Murinae Illiger, 1811
Genus *Apodemus* Kaup, 1829
Subgenus *Sylvaemus* Ognev & Vorobiev, 1923
Apodemus (Sylvaemus) sylvaticus (Linnaeus, 1758)

Material: 18 maxillaries mostly fragmented, 9 mandible fragments, 11 M1, 4 M2, 4 M3, 11 m1, 4 m2, 2 m3, 2 humeri and 2 femuri from the late Pleistocene breccia; 15 maxillaires, some of which are fragmented, 26 mostly fragmented mandibles (Fig. 2E-F), 3 M1, 1 M2, 1 M3, 1 m1, 4 m2, 1 m3 and 2 femora from Holocene soil.

Description and remarks: The morphologic features of fossil remains are typical of the genus *Apodemus*, in particular M1 with four roots, m1 with two roots and six main cusps in two rows and m1 and m2 with accessory cusps on the labial side (Capizzi, 2008). The distinct and well-developed tubercle t3 of the M2, the three-rooted M3, and the tubercles of the lower molars that form relatively complex patterns, are typical of the *Sylvaemus* subgenus (Capizzi & Filippucci, 2008a). Furthermore, the M1 with the confluent tubercles t4 and t7 and the M2 with the developed tubercle t9 are features attributing the above specimens to *A. sylvaticus*, the Wood mouse (Niethammer, 1978; Capizzi & Filippucci, 2008b). Some upper and lower molars have absent or incomplete

roots, a humerus has an unfused proximal epiphysis, and a femur has an unfused distal epiphysis. Therefore, these latter specimens belonged to immature individuals.

According to recent biomolecular studies, the Sicilian population of *A. sylvaticus* would be genetically isolated and therefore could represent a different taxon (Amori & Castiglia, 2018; Loy et al., 2019).

Apodemus cf. *A. sylvaticus* occurs in Sicily since the San Teodoro FC (Bonfiglio et al., 2003; Masini et al., 2008; Petruso et al., 2011a; Marra, 2013), and it is also recorded, sometime as *A. sylvaticus*, in some Lateglacial and Holocene sites (Tagliacozzo, 1993; Burgio et al., 2005; Surdi, 2008; López-García et al., 2013).

Nowadays, *A. sylvaticus* is distributed throughout western Europe, northern Africa, Sicily and other western Mediterranean islands (Niethammer, 1978; Capizzi & Filippucci, 2008b). Adaptable and opportunistic species, the Wood mouse frequents environments with shrub cover, and its optimal habitat is the forest, where the tree cover offers shelter from predators and availability of food for a good part of the year (Tellería et al., 1991; Montgomery, 1999; Marsh & Harris, 2000; Capizzi & Filippucci, 2008b). In Sicily, the species occurs up to 1800 m a.s.l., preferring forests and Mediterranean maquis, and avoidings arid and dry environments (Cagnin & Grasso, 1999; Sarà, 2008c). It is also recorded in the Hyblaean Mountains (Siracusa, 1997; Sarà, 2008c; Aprile et al., 2010).

5. TAPHONOMIC REMARKS

The non-volant micromammal remains recovered from Grotta dei Pipistrelli comprise 279 taxonomically identified specimens, belonging to at least 79 individuals (Tab. 1), and, in addition, over 200 isolated incisors referable to small-sized rodents.

The micromammal assemblages are composed of disarticulated cranial and postcranial remains. Isolated teeth are the most numerous elements, followed by fragmented maxillae and mandibles. The relative abundance of these skeletal elements and their fragmentation can be attributed to the destructive action of predators (Andrews, 1990; Fernández-Jalvo et al., 2016), but also to post-depositional processes (Andrews, 1990; Salari, 2014) and/or to methods of sampling and processing in the laboratory (Salari, 2014; Salari et al., 2019). Fossil remains show different colours from havana white to orange ochre and dark brown: predominantly havana white with some calcium carbonate concretions from the late Pleistocene breccia, mostly or-

ange ochre with rare specimens tending to dark brown from the Holocene soil.

The modifications observed on the teeth concern the reduction or removal of the enamel along the half height in *M. savii* group molars, and a loss of shininess or enamel reduction at the crown-root junction in *A. sylvaticus* molars. The incisors of the two rodents, particularly those isolated, display loss of shininess all over the tooth or enamel retraction on the tip leaving the dentine exposed and rounded. A significant percentage of the analysed fossil remains (ca. 15%) shows these peculiar preservations caused by digestion (Andrews, 1990; Fernández-Jalvo et al., 2016), indicating that the bones and teeth were accumulated by predators.

Considering the molars only (Tab. 2), the very high percentage of teeth without alteration shows that the main agent responsible for the accumulation was probably a "category 1" predator, with a light capability for modification. According to Fernández-Jalvo et al. (2016), "category 1" for the molars includes nocturnal predatory birds, such as *Tyto alba* (Scopoli, 1769), *Asio flammeus* (Pontoppidan, 1763), *Asio otus* (Linnaeus, 1758) and *Bubo lacteus* Temminck, 1820. *Tyto alba* prefers to hunt along the edges of woods, it is a generalist and opportunistic predator catching the prey in the nearby surroundings (Andrews, 1990; Fernández-Jalvo et al., 2016). *Asio flammeus* generally hunts in the meadows and wetlands close to coastal plains, it is an opportunistic predator that preferably feeds on arvicolines (Andrews, 1990; Fernández-Jalvo et al., 2016). *Asio otus* usually hunts in open environments, it is a selective predator that mostly prey the arvicolines (Andrews, 1990; Fernández-Jalvo et al., 2016). These three strigiforms are part of the Italian avifauna, including Sicily (Galeotti, 2003; Ientile & Massa, 2008) and Pantalica Nature Reserve (AA.VV., 2009, and unpublished data), and possibly were it throughout the latest Pleistocene and middle Holocene. Instead, *B. lacteus* is a bird of prey distributed through most of sub-Saharan Africa (Andrews, 1990).

Considering the incisors only, the modifications observed are mostly on the tip, indicating that the teeth were retained in the jaws during digestion (Andrews, 1990; Fernández-Jalvo et al., 2016). This, combined with the percentages showing different degrees of digestion (Tab. 2) suggest that the main agent responsible for the accumulation was probably a "category 2" predator. This category, for the incisors, includes *A. otus*, *B. lacteus*, *Strix nebulosa* Forster, 1772 and *Bubo scandiacus* (Linnaeus, 1758) (Fernández-Jalvo et al., 2016). Both *S. nebulosa* and *B. scandiacus* are species distributed in

Taxon	Pleistocene breccia				Holocene soil			
	NISP	%	MNI	%	NISP	%	MNI	%
Crocidura sicula	3	2,3	2	6,5	2	1,4	2	4,2
Microtus savii group	62	46,6	12	38,7	89	61,0	24	50,0
Apodemus sylvaticus	68	51,1	17	54,8	55	37,7	22	45,8
Total	133	100	31	100	146	100	48	100

Tab. 1 - Grotta dei Pipistrelli (Sicily, Italy): number of identified specimens (NISP) and minimum number of individuals (MNI) of taxa identified, and their percentage ratios.

	Pleistocene breccia								Holocene soil							
	Microtus		Apodemus		small-sized rodents		Total		Microtus		Apodemus		small-sized rodents		Total	
	n.	%	n.	%	n.	%	n.	%	n.	%	n.	%	n.	%	n.	%
Molars	63		77				140		98		88				186	
Absent	61	96.8	76	98.7			137	97.9	96	98.0	87	98.9			183	98.4
Light - Moderate	2	3.2	1	1.3			3	2.1	2	2.0	1	1.1			3	1.6
Heavy - Extreme	0	0.0	0	0.0			0	0.0	0	0.0	0	0.0			0	0.0
Incisors	2		2		98		102		14		16		112		142	
Absent	1	50.0	1	50.0	68	69.4	70	68.6	11	78.6	12	75.0	76	67.9	99	69.7
Light - Moderate	1	50.0	1	50.0	29	29.6	31	30.4	3	21.4	4	25.0	36	32.1	43	30.3
Heavy - Extreme	0	0.0	0	0.0	1	1,0	1	1,0	0	0.0	0	0.0	0	0.0	0	0.0

Tab. 2 - Grotta dei Pipistrelli (Sicily, Italy): number and percentages of teeth showing different degrees of digestion.

higher latitudes and absent in the Mediterranean basin (Cramp, 1985). Only during the colder stages of the late Pleistocene these strigiforms reached southern Europe, but *S. nebulosa* has been never recorded beyond the North-East Italy (Tyberg, 2008), while *B. scandiacus* reached also southern Italy, but not Sicily (Petruso et al., 2008; Tyberg, 2008).

Thus, taking into account all these considerations on the degrees of digestion on the molar and incisor surfaces and the habits of the nocturnal predatory birds, we assume that the long-eared owl, *A. otus*, was the main agent responsible for the accumulation of the analysed remains.

The long-eared owl as the assumed selective bird of prey usually hunts in open environments (Andrews, 1990; Fernández-Jalvo et al., 2016), so arvicoline remains would be overestimated, and their relative frequency in the environment could be lower than in the pellets. However, several exceptions in which the percentages of arvicolines in the current *A. otus* pellets are lower than those of the murines, are recorded in Italy (e.g., Casini & Magnani, 1988; Siracusa et al., 1996; Castioni et al., 1998; Cecere et al., 2013). In particular, Siracusa et al. (1996) showed that in the diet of the long

-eared owl from Sicily the main prey is *M. savii* at Roccapalumba (500 m a.s.l., near Palermo), while at Linguaglossa (1400 m a.s.l., on the Etna volcano) the main prey is *A. sylvaticus*. In this last site, the bone remains of the murid species are about twice the amount of those of *M. savii*, with percentages similar to those of the *Strix aluco* (Linnaeus, 1758) pellets of the same area (Siracusa et al., 1996). The latter bird of prey is a generalist predator (Andrews, 1990; Fernandez-Jalvo et al., 2016). Thus, in different environments *A. otus* sometimes orients its predation on different preys according to the availability of the territory (Siracusa et al., 1996). It cannot be excluded that, because the low biodiversity in the Hyblaean plateau in the times analyzed here, *A. otus* behaved as a flexible and non-selective predator.

6. DISCUSSION

6.1. Palaeoclimatic and palaeoenvironmental considerations

According to the three radiometric dating, the micromammal assemblages from Grotta dei Pipistrelli come from two distinct chronological horizons: one referred to the LGM and, therefore, attributable to the Castello FC, and the other to the middle Holocene.

All identified small mammal taxa (Tab. 1) are still part of the extant Sicilian fauna (AA.VV., 2008; Amori et al., 2008) and nowadays occur in the Pantalica Nature Reserve (Tab. 3). Both latest Pleistocene and middle Holocene assemblages are oligotypicals and similar to each other.

It seems appropriate to specify that, among Eulipotyphla and Rodentia, only *Erinaceus europaeus* Linnaeus, 1758, *Crocidura* cf. *C. sicula*, *M. savii* group and *Apodemus* cf. *A. sylvaticus* occur in Sicily during the latest Pleistocene (Bonfiglio et al., 2003; Masini et al., 2008; Petruso et al., 2011a; Marra, 2013). In the early Holocene, *Arvicola amphibius* Linnaeus, 1758 and *Glis glis* Linnaeus, 1766 first occur, but are so far recorded only in northwestern Sicily (Petruso et al., 2011a). The other species of the current Sicilian small mammal fauna reached the island in the late Holocene, voluntarily or involuntarily brought by humans (Masseti, 2002; Petruso et al., 2011a), while *A. amphibius* becomes extinct in the

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Erinaceus europaeus Linnaeus, 1758 - European hedgehog

Crocidura sicula Miller, 1900 - Sicilian shrew

Suncus etruscus (Savi, 1822) - Etruscan pygmy shrew

Eliomys quercinus (Linnaeus, 1766) - Garden dormouse

Glis glis (Linnaeus, 1766) - Edible dormouse

Microtus nebrodensis (Minà-Palumbo, 1868) - Sicilian vole

Apodemus sylvaticus (Linnaeus, 1758) - Wood mouse

Mus musculus Linnaeus, 1758 - House mouse

Rattus rattus (Linnaeus, 1758) - Black rat

Tab. 3 - List of non-volant small mammals that currently occur within the Natural Reserve "Pantalica, Valle dell'Anapo e Torrente Cava Grande" (AA.VV., 2008, 2009, and unpublished data). *E. europaeus*, *Crocidura* cf. *C. sicula*, *Microtus savii* group and *Apodemus* cf. *A. sylvaticus* occur in Sicily since late Pleistocene, *G. glis* from the early Holocene, *S. etruscus*, *E. quercinus*, *M. musculus* and *R. rattus* only from the recent Holocene (Petruso et al., 2011a).

region (Catalisano & Sarà, 1995). Furthemore, *E. europaeus* and *G. glis* are not currently included in the usual diet of *A. otus* (see Sarà, 1990; Capizzi & Luiselli, 1998; Riga & Capizzi, 1999; Sergio et al., 2008). Thus, the three taxa of micromammals from Grotta dei Pipistrelli include all, or almost all, of the potential mammalian prey available for *A. otus* in Sicily in the times examined.

Taking into account these considerations, the habitat preferences of each taxon (see 4. Systematic notes) and their percentages (Tab. 1), the taphonomic observations (see 5. Taphonomic remarks) and the current non-volant micromammal fauna of the Pantalica Nature Reserve area (Tab. 3), the landscape inferred from the analysed assemblages seems to be rather similar to the present, with woodlands alternated with large clearings and bushes. The frequencies, particularly of the rodents, indicate a palaeoenvironment slightly more wooded in the LGM (*A. sylvaticus* dominant species) than in the middle Holocene (*M. savii* increases and *A. sylvaticus* decreases). Despite the limited amount of taxa, these results are sufficiently in agreement with previous studies on the bats that suggested an environment prevalently wooded during the LGM and progressively open in the middle Holocene (Salari et al., 2019).

Adding the data of Chiroptera to those of non-volant micromammals, there is a greater number of taxa (Tab. 4) and it is possible to reduce any biases due to the assumed selectivity of the predator. According to Salari et al. (2019), the bat assemblages are essentially autochthonous thanatocoenoses, coming mainly from the natural accumulation of animal bones that roosted and died in the cave. Some ecological and biogeographical features of bats are summarised in Table 5.

The ecological features of all the taxa recovered in Grotta dei Pipistrelli allow the outline of a composite landscape near the cave, with wooded areas interrupted by open spaces (grassland, steppe), shrubland and rocky areas. Even in this case, the palaeoenvironment seems to be more wooded in the LGM than in the middle Holocene. Indeed, the small mammals of woods and forests are dominant in the LGM, more numerous than the taxa indicading open spaces and various or mixed environments together (Fig. 3). In the middle Holocene, the taxa indicating woods and forests are still dominant, but they decrease together with those of various or mixed environments, to the advantage of the open spaces taxa (Fig. 3).

Bat assemblages with dominant *M. myotis* and/or *M. blythii*, accompanied by *M. schreibersii*, auxiliary species, and *M. capaccinii* and rhinolophids, accidental species, are typical Mediterranean associations and would point to relatively warm climate conditions in the region (Salari et al., 2019). This, combined with the abundance of *A. sylvaticus* compared to *M. savii* group (Tabs 1 and 4), suggests that Sicily (or at least this area of South-East Sicily) kept temperate-warm and humid climatic conditions even during the LGM. Global Holocene warming is reflected by the increase of clearly thermophilous species, such as *R. mehelyi* and *M. blythii*, and by the disappearance of *Plecotus* cf. *P. auritus* (Tab. 4).

6.2. Comparisons with other fossil assemblages of Sicily and the southern Tyrrhenian Sea

Temperate-warm climatic conditions during the LGM in the Hyblaean Mountains would disagree with the indications suggested by planktonic foraminiferal assemblages of marine sedimentary successions. These unicellular organisms are very sensitive to the water masses conditions where they live and suggested that during the last Pleiniglacial the surface waters were on average about 4-6 °C colder in the Sicilian Channel and around 8-9 °C in the southern Tyrrhenian Sea compared to present (Sbaffi et al., 2001; Hayes et al., 2005; Incarbona et al., 2010).

According to the fossil pollen record and the ratio of oxygen isotopes in the sediments of Pergusa Lake (674 m a.s.l.), in central Sicily, the vegetation around the LGM was characterized by the scarce presence of trees, while the herbaceous and shrubby flora (Asteraceae and Chenopodiaceae), indicative of an open environment of steppe or semi-steppe, was quite common (Zanchetta et al., 2007; Sadori et al., 2008). However, the Lateglacial reforestation showed that the surrounding of Pergusa Lake played an important role in preserving plant biodiversity, including some mesophilous and thermophilous plant species of Angiosperm trees, even around the LGM (Sadori et al., 2008).

Lateglacial mammal assemblages of Sicily referred to Castello FC indicate a rather arid climate, as it can be implied from the occurrence of *E. hydruntinus* and the relative abundance of *M. savii* group (Masini et al., 2008; Petruso et al., 2008, 2011a). However, there are no cold climate indicators on the island (Martini et al., 2007; Masini et al., 2008). Probably, the steppe environment was due to the extremely low rainfall not associated with

Taxon	Last Glacial Maximum	middle Holocene
Crocidura sicula	2,1	1,1
Rhinolophus ferrumequinum	3,2	2,7
Rhinolophus euryale	2,1	1,6
Rhinolophus mehelyi	2,1	4,4
Myotis myotis	10,5	15,4
Myotis blythii	3,2	7,1
Myotis myotis/blythii	29,5	29,7
Myotis capaccinii	2,1	1,1
Myotis cf. *M. mystacinus*	-	0,5
Plecotus cf. *P. auritus*	2,1	-
Miniopterus schreibersii	12,6	11,0
Microtus savii group	12,6	13,2
Apodemus sylvaticus	17,9	12,1
MNI	95	182

Tab. 4 - Grotta dei Pipistrelli (Sicily, Italy): percentages of all the taxa recovered in the cave according the minimum number of individuals (MNI). Data of Chiroptera by Salari et al. (2019).

Species	Foraging environment	Roosting habits	Zoogeographical patterns
Rhinolophus ferrumequinum	habitat mosaics: pastures interspersed with hedgerow and broadleaved woodland, and wetland up to 2000 m a.s.l.	caves; small nursery and hibernation colonies	Mediterranean s.l.
Rhinolophus euryale	karstic habitats with broadleaved woodland and scrubland up to 1000 m a.s.l.	caves; middle nursery colonies, smaller hibernating colonies	Mediterranean s.s.
Rhinolophus mehelyi	karstic habitats with broadleaved woodland and scrubland up to 1200 m a.s.l.	caves; middle nursery colonies, smaller hibernating colonies	Mediterranean s.s.
Myotis myotis	woodland and forest with sparse undergrowth up to 2200 m a.s.l.	caves; massive nursery colonies, smaller hibernating colonies	Mediterranean s.l.
Myotis blythii	open areas, meadows with tall grass, steppes, pastures up to 1000 m a.s.l.	caves; massive nursery colonies, smaller hibernating colonies	Mediterranean s.l.
Myotis capaccinii	woods with shrubs and mainly wetlands up to 830 m a.s.l.	caves; middle to massive nursery colonies, smaller hibernating colonies	Mediterranean s.s.
Myotis mystacinus	forests or open areas close to wetlands up to over 2000 m a.s.l.	caves, tree-holes; middle to small nursery and hibernating colonies	Nemoral
Plecotus auritus	mature woodlands up to over 2000 m a.s.l.	tree-holes, caves; nursery colonies, solitary hibernation	Boreal
Miniopterus schreibersii	various: forest and open habitats, herbaceous vegetation areas and steppes up to 1230 m a.s.l.	caves; massive nursery and hibernation colonies	Mediterranean s.s.

Tab. 5 - Synthesis of some ecological attributes of the bats (Lanza, Agnelli, 2002; Agnelli et al., 2008; Salari et al., 2019); s.s.: *sensu stricto*; s.l.: *sensu lato*.

very low temperatures unlike, in particular, the Adriatic side and inner Apennine of southern Italy (Huntley et al., 1999; Petronio et al., 2007; Popov et al., 2014, among others). Furthermore, the mammal assemblages show remarkable affinity with the coeval faunas of the South Italy, in particular with those of the Tyrrhenian side with the constant presence of red deer and wild boar (Masini et al., 2008; Petruso et al., 2011a) indicating the local spread of arboreal cover.

These still scarce and fragmented data, however, suggest that, in a framework of global cooling, as attested by marine plankton, the environments of the island were diversified. Probably, the paleoenvironment and the paleoclimate in the latest Pleistocene were also connected to the physiography of the territory, to altitude above sea level and to the rainfall regime.

In the middle Holocene, a tendency to a progressive extension of open landscapes in the surrounding of Grotta dei Pipistrelli is suggested by the bat fossil remains (Salari et al., 2019), and seems to have now been confirmed by the non-volant micromammal remains. This is also in agreement with the palaeoenvironmental indications provided by the
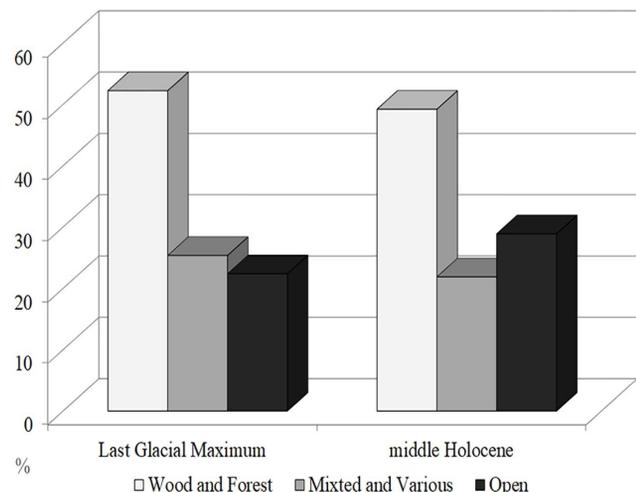

Fig. 3 - Grotta dei Pipistrelli (Sicily, Italy): percent ratio of the number of individuals according to the prevailing environment. Wood and Forest: *Rhinolophus euryale, Rhinolophus mehelyi, Myotis myotis, Myotis capaccinii, Plecotus* cf. *P. auritus* and *Apodemus sylvaticus*; Mixed and Various: *Crocidura sicula, Rhinolophus ferrumequinum, Myotis* cf. *M. mystacinus* and *Miniopterus schreibersii*; Open: *Myotis blythii* and *Microtus savii* group.

pollen and microcharcoal succession from Pergusa Lake (Sadori & Giardini, 2007; Sadori et al., 2008, 2013), and by the small mammal assemblages from northwesttern Sicily, such as Grotta dell'Uzzo (Tagliacozzo, 1993), near San Vito Lo Capo, and Vallone Inferno (López-García et al., 2013), in the Madonie Mountains. Indeed, according to Sadori et al. (2008, 2013), the wettest conditions of early Holocene occurred in the mainland Sicily at about 9,000 years BP, lasted until about 7,200 years BP, are followed by a trend towards very dry conditions at about 3,000 years BP. It is interesting to note that the beginning of the trend towards dry conditions recorded in Pergusa Lake is more or less in the same time as the Grotta dei Pipistrelli Holocene samples. In contrast, the pollen successions from Gorgo Basso, Preola Lake and Biviere di Gela, coastal lakes in South Sicily, indicate that evergreen broad-leaved and deciduous forests expanded in these times at the cost of open communities (Noti et al., 2009; Tinner et al., 2009; Calò et al., 2012). Nevertheless, the hydrological regime of Preola Lake recorded a dry phase between 8,300 and 7,000 years BP (Magny et al., 2011). In these cases, the distance from the sea and the altitude above sea level seem to be the mainly causes of the variability and spatial differences in the environmental responses to climate changes.

7. CONCLUSIONS

A species of Eulipotyphla, *Crocidura sicula*, and two taxa of Rodentia, *Microtus savii* group and *Apodemus sylvaticus*, were recognized in the fossil assemblages from Grotta dei Pipistrelli (South-East Sicily, Italy). These taxa occur in the mammal assemblages of Sicily since San Teodoro FC and they are still part of the extant fauna. Nowadays, they also occur in the Hyblaean Mountains and in the Pantalica Nature Reserve.

According to three ^{14}C radiometric dating, the small mammal remains were deposited in the latest Pleistocene, during the LGM, and in the middle Holocene. Taphonomic remarks suggest that the two assemblages of non-volant micromammals probably come from pellets accumulated by *Asio otus*. Both the assemblages are oligotypical and similar to each other. Nevertheless, the percentage variations in the recognized taxa suggest that the palaeoenvironment was slightly more wooded during the LGM than in the middle Holocene.

With the addition of the data on Chiroptera from the same samples, the ecological features of all the identified taxa allow the outline of a composite landscape predominantly wooded with temperate-warm and humid climatic conditions in the surrounding of the cave, in both the LGM and middle Holocene, but slightly less wooded during the middle Holocene than in the LGM.

The Sicilian faunistic changes in the latest Pleistocene were probably less influenced by the climate than the palaeogeographic evolution of the island. Palaeoenvironmental and palaeoclimatic conditions in the LGM seem to be more connected with the physiography of the territory, the altitude on sea level and the low rainfall rather than the low temperatures. Pergusa Lake, in central Sicily, is an endorheic basin, without tributaries, and

the scarce rainfall have certainly favored the lowering of the lake level and the development of a prevalently open environment, such as steppe or semi-steppe. In contrast, low rainfall have probably not dried up the waterways of the Pantalica Nature Reserve territory, in the Hyblaean plateau, and the water supply provided by Anapo River and its tributaries was great enough to support a rich and diversified vegetation cover, which hosted the micromammal communities and their predators.

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