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Anthropogenic impacts on vegetation landscapes and environmental implications during the Middle-Late Holocene in the Iberian Central Pre-Pyrenees: An anthracological approach

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ABSTRACT

Cova Colomera is one of the most important archaeological sites to explain early herding activities in the Central Pre-Pyrenees (Iberian Peninsula). Fieldworks have provided a stratigraphy that shows short occupations of the cave by Neolithic and Bronze Age human groups. The sedimentological description has revealed fumiers deposits, that are characteristic of husbandry activities. In this paper, we provide the anthracological results based on 1117 charcoal fragments. The results allow to characterise the Mediterranean vegetation landscape and its transformation, from a local perspective, related to climatic changes and anthropogenic activities.

Climate changes and human activities have played a significant role in Mediterranean landscapes dynamics. However, the incidence or impact of both agents on the vegetation landscape occurred unequally among the Mediterranean region. The anthracological results from Cova Colomera suggest that the Central Pre-Pyrenees was dominated by an oak forest ecosystem, with sub- and supra-Mediterranean deciduous taxon and coniferous forest during the Middle Holocene. This ecosystem remained more or less stable during the Late Holocene, although evergreen oak showed a slight increase, and coniferous forest showed a slight decrease. The orographic characteristics of the Central Pre-Pyrenees were able to maintain temperate and humid conditions, with less impact of aridity events recorded in Mediterranean environments. From a diachronic point of view, the herding activities of Neolithic human and Bronze Age human groups do not appear to have affected highly the landscape development of the Central Pre-Pyrenees. Human activities were probably not intensive in terms of forest clearing or land use.

1. Introduction

The impact of general Holocene climate dynamics varied among past Mediterranean landscapes. Above all in the first stages of the Holocene (11.7 ka BP to 4.2 ka BP), the influence of climatic agents on landscape transformation was more evident than the impact of human activities. However, it is more controversial, or less obvious, which of the two agents, natural factors or the human activities, has been the main contributor to landscape transformation since the Middle-Late Holocene Boundary (4.2 ka BP), or indeed whether it has been a combination of both (see Jalut et al., 2000; Roberts et al., 2011). Holocene Mediterranean woodland history and landscape changes are here studied using a palaeoecological proxy, mainly pollen and charcoal data (e.g., Jalut et al., 2009; Woodbridge et al., 2018; Roberts et al., 2019; Picornell-Gelabert et al., 2020). According to the available palaeobotanical sequences in the NE Iberian Peninsula, at the end of the Late Pleistocene and the beginning of the Early Holocene, deciduous oak forest, broadleaf trees and pine forests were dominant in the area (Riera-Mora and Esteban-Amat, 1994; Burjachs et al., 1997; Riera et al., 2007; Allué et al., 2007, 2017; Carrión et al., 2010a; Pérez-Obiol et al., 2011; Fletcher et al., 2012; Revelles et al., 2015, 2018; González-Sampériz et al., 2017; Allué and Mas, 2020; Mas et al., 2021). Further, during the Middle Holocene sub-epoch (8.2–4.2 ka BP), warmer and more humid climatic conditions prevailed as high-precipitation regimes increased, favouring the expansion of deciduous forests and the retreat of pine forests and grasslands (Badal et al., 1994; Jalut et al., 2009; Allué et al., 2012; González-Sampériz et al., 2017). Simultaneously, from the Early Holocene, Neolithization throughout the Mediterranean resulted in the expansion of agriculture and herding associated with the development of a sedentary lifestyle. Herding activities are evidenced in archaeological sites by fumier deposits, which have been documented from the Early Neolithic

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to the Iron Age (see Angelucci et al., 2009). Fumiers are the result of stabling animals (usually flocks of goat and sheep) within the entrance areas of caves and rock-shelters. The deposits are mainly derived from the combustion of organic waste, such as accumulations of animal dung. Plant material in this type of deposit has different origins related to practices and needs associated with human settlements such as foddering, animal beds, fuel, refuse and fencing (Brochier, 1983, 1991, 1996; Polo-Díaz et al., 2014, 2016; Burguet-Coca et al., 2020).

In addition to being an important proxy for detecting different past local landscapes, anthracology is also able to identify changes in human-forest relationships in terms of wood exploitation and consumption (see Chabal, 1992; Chabal et al., 1999; Kabukcu, 2018; Asouti and Kabukcu, 2021; Kabukcu and Chabal, 2021). Anthracological data available for the NE Iberian Peninsula during the Middle Holocene and Late Holocene sub-epochs (Senabre and Socias, 1993; Heinz and Vernet, 1995; Ros, 1995a, 1995b, 1996, 1998; Piqué, 1999, 2005; Allué, 2007, 2010; Martín Seijo and Piqué Huerta, 2008; Allué et al., 2009; Vila and Piqué, 2012; Antolín et al., 2013; Alcolea, 2017; Daura et al., 2019) indicate that the configuration and distribution of vegetation landscapes were diverse at regional scale. As a consequence, research based on a local approach may be relevant to reconstructing the regional variability (Fig. 1).

The Central Pre-Pyrenees (southern Pyrenees, Iberian Peninsula) is remarkable for the evidence of herding activities that occurred there, as documented at Cova Colomera (see Bergadà and Oms, 2021; Martín and Oms, 2021) and also at other archaeological sites where anthracological data are available (Polo-Díaz et al., 2016; Burguet-Coca et al., 2020). The present study of a new anthracological sequence from a fumier deposit in Cova Colomera (Serra del Montsec, Central Pre-Pyrenees), with human occupations from the Early Neolithic to the Middle Bronze Age (mid-6th millennium cal BCE to 3rd millennium cal BCE), assumes a diachronic perspective in order to understand the role of anthropogenic activities and climate change in the transformation of local environments and the shaping of the cultural landscape. The main objectives are to understand vegetation change and its causes, and thus to estimate the impact that the Neolithization process may have had on vegetation landscapes.

1.1. Geographical area and landscapes

The study area is located in the Montsec range, in the Central Pre-Pyrenees, between the Tremp-Graus and Ager drainage basins. This range, rising through the passage of the Pre-Pyrenees towards the Ebro Basin, is formed by Cretaceous bioclastic limestones. The

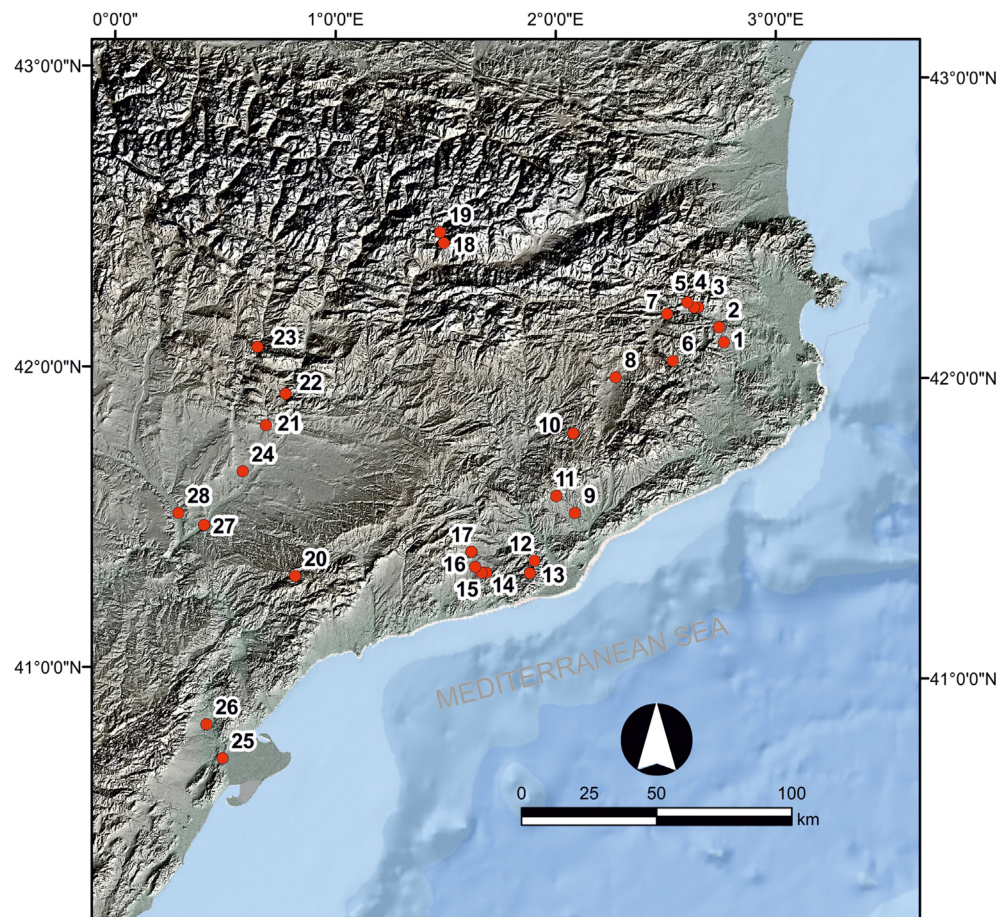

Fig. 1. Archaeological sites with available Middle-Late Holocene anthracological data from NE Iberian Peninsula. Early Neolithic: 1) La Draga (Piqué, 2005); 2) Cova d'en Pau III (Ros, 1996; Piqué, 2005); 3) Cova 120 (Ros, 1995a; Piqué, 2005); 4) Bauma del Serrat Pont (Piqué, 2005); 5) Plansallosa (Ros, 1995a; Piqué, 2005); 6) Cova de l'Avellaner (Ros, 1996); 10) Cova del Toll (Mas and Allué, 2020); 11) Cova del Frare (Ros, 1996); 12) Cova Bonica (Daura et al., 2019); 13) Can Sadurní (Antolín et al., 2013); 15) La Serreta (Allué, 2010); 17) Cova de la Guineu (Allué et al., 2009); 18) Camp del Colomer (Piqué et al., 2018); 19) Bauma Margineda (Heinz and Vernet, 1995); 20) Coves del Fem (Alcolea, 2017); 23) Cova Colomera (in this paper); 25) Barranc d'en Fabra (Ros, 1996); 26) Cova del Vidre (Alcolea, 2017). Late Neolithic-Chalcolithic: 3) Cova 120 (Ros, 1995a; Piqué, 2005); 4) Bauma del Serrat Pont (Piqué, 2005); 7) La Prunera (Piqué, 2005); 14) Santa Maria dels Horts (Senabre and Socias, 1993); 17) Cova de la Guineu (Allué et al., 2009); 21) Cova Gran de Santa Linya (Allué, unpublished); 22) Auvelles (Martín Seijo and Piqué Huerta, 2008); 23) Cova Colomera (in this paper); 24) Roques del Sarró (Vila and Piqué, 2012). Early Bronze age: 8) Institut Manlleu (Ros, 1995b); 9) Can Roqueta (Piqué, 1999); 10) Cova del Toll (Mas and Allué, 2020); 16) Mas d'en Boixos (Allué, 2007); 17) Cova de la Guineu (Allué et al., 2009); 23) Cova Colomera (in this paper). Middle Bronze age: 21) Cova Gran de Santa Linya (Allué, unpublished); 23) Cova Colomera (in this paper); 27) Genó (Vila and Piqué, 2012); 28) Punta Farisa (Ros, 1998).

topography is the result of a series of monoclinal mountain ranges over 40 km, covering an area of 186.96 km2, oriented from west to east. Three rivers, the Boix, the Noguera Pallaresa and the Noguera Ribagorçana, cut through the ridge from north to south. Crossing the Montsec range, these water courses have eroded and shaped narrow gorges and routes such as Pas Nou, Terradets and Mont-rebei. At some points, the range exceeds 1600 m a.s.l. in its central sector (e.g., Sant Alís is at 1676 m a.s.l.), but it loses height at either end.

The southern slope of the range, the Ager basin, is characterised by a longer summer drought and therefore drier climate conditions. Locally, the area is under the influence of a sub-Mediterranean climate type, albeit with a continental trend (sensu Carreras and Ferré, 2014). Climatic conditions of sub-Mediterranean climate type are differentiated from the general Mediterranean regime by cooler temperatures and higher rainfall, although a short and irregular summer drought may occur in some years (see Jalut et al., 2000). The mean annual rainfall ranges from 400 to 600 mm, with the maximum precipitation occurring in autumn (October showing mean precipitation of around 40 mm) and the minimum in summer (July showing precipitation of less than 13 mm). The mean annual temperature oscillates between 11 and 13 °C, with a maximum of 31 °C in July and a minimum of 0 °C in January (Meteocat data 2020 from Camarasa municipality) (Fig. 2). The biome of the area is characterised by Mediterranean forests, woodlands and scrub belonging to the Iberian sclerophyllous and semi-deciduous forests (Dinerstein et al., 2017). In some areas, holm-oak forests (*Quercus ilex* subsp. *ilex*) and Aleppo pine forests (*Pinus halepensis*) expand.

The northern slope of the range, the Tremp-Graus Basin, is rainier and shadier, and consequently the climate is more temperate and could be interpreted as Eurosiberian in tendency. The biome is characterised by a temperate broadleaf and mixed forest, which belongs to the Pyrenees conifer and mixed forest ecoregion (Dinerstein et al., 2017). Locally, beech forests and oak forests are predominant (*Quercus faginea*, *Quercus cerrioides* and *Quercus pubescens*, with the presence of *Acer* sp. and *Buxus sempervirens*). Likewise, in the higher areas of the range, pine forests expand (*Pinus nigra* subsp. *salzmannii* and *Pinus sylvestris*).

2. Cova Colomera

Cova Colomera is located in the Mont-rebei gorge, Serra del Montsec (Central Pre-Pyrenees, NE Iberian Peninsula). The cave is located 670 m

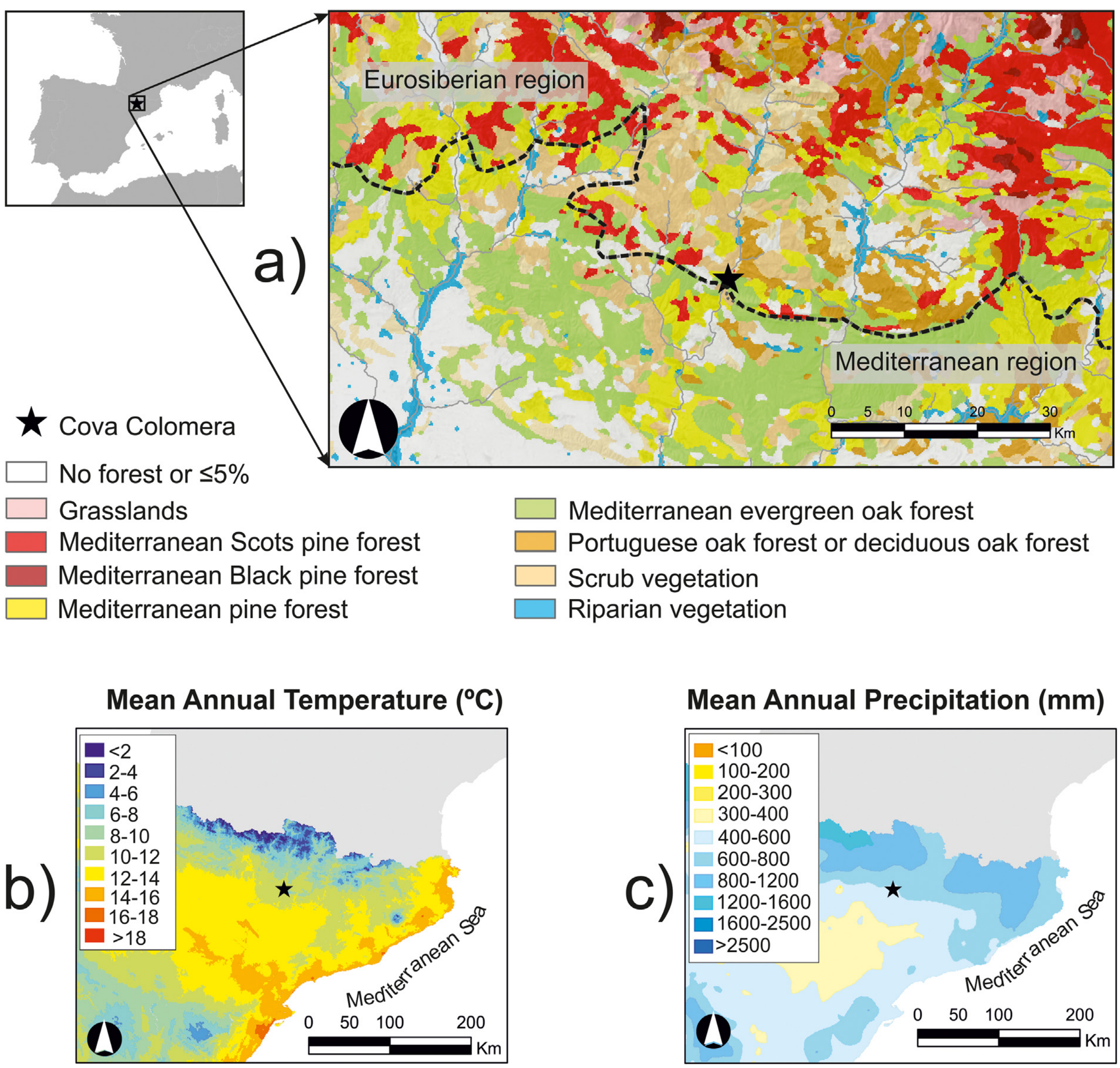

Fig. 2. A) Map of forest communities in the study area, according to the vegetation series of Spain (Rivas-Martínez, 1987); B and C) Principal bioclimatic variables in the NE Iberian Peninsula. "Mean annual Temperature" (B) and "Mean annual Precipitation" (C) according to *Ministerio de Agricultura, Pesca y Alimentación* (Spanish government), by geostatistical interpolation methods from actual AMET data (http://wms.mapama.es/sig/Agricultura/CaractAgroClimaticas/wms.aspx?).

a.s.l., 150 m above the left bank of the Noguera Ribagorçana River, a tributary of the Segre River (Oms et al., 2008, 2009a) (Fig. 3). The cave entrance is 70 m high and 30 m wide and leads to a chamber about 180 m long and 10–12 m wide (Oms et al., 2013).

From 2005 to 2011, an interdisciplinary team from the Seminari d'Estudis i Recerques Prehistòriques (SERP-UB) excavated the cave, resulting in the description of the stratigraphic sequence (Oms et al., 2015). Two 26 m2 test pits were excavated during the fieldwork: one in the eastern sector of the cave, "Colomera Est (CE)", and the second, "Colomera Vestíbul (CV)", in the highest sector of the cave entrance. The CV test pit revealed thin stratigraphic layers up to the top of a carbonate crust. Under the crust, a series of overlapping anthropogenic structures (silos, hearths, post-holes) were documented. Six Holocene archaeological layers and one Late Pleistocene layer were registered in the CE test pit (Table 1).

The lowest unit CE15 (CE15a, b and c), corresponding to the Pleistocene, was not anthropic in origin, but many micro- and macrofaunal remains were recovered from the excavation and sediment sieving (López-García et al., 2010). The Pleistocene unit was separated from the Holocene sequence by a thin concentration of boxwood leaves and white-coloured branches that corresponds to the top unit of the Holocene sequence, layer CE14 (7163–6964 cal. years BP). The boxwood remains, such as branches and leaves, were documented in a primary position and have been interpreted as a bed for the herd or as part of their diet (Oms et al., 2013; Bergadà and Oms, 2021). Layers CE14, CE13 (7164–6909 cal. years BP) and CE12 (7146–6737 cal. years BP) are ascribed to a late phase of the regional Early Neolithic (Oms et al., 2008, 2009a, 2010, 2013, 2015). Layers CE10 (5305–5041 cal. years BP) and CE9 (4863–4621 cal. years BP) are ascribed to the Late Neolithic, with horizons associated with the Veraza and Veraza-Ferrières cultures respectively (Oms et al., 2010, 2015). In turn, EE1 (4084–3839 cal. years BP, 4086–3896 cal. years BP) is an Early Bronze Age silo-shaped negative structure cutting through the Early Neolithic layers (Oms et al., 2009b, 2010, 2015). Lastly, layer CE8 (3579–3395 cal. years BP, 3561–3400 cal. years BP) corresponds to the Middle Bronze Age. All the Holocene layers correspond to an in-situ sedimentary facies of a fumier type (sensu Brochier, 1983, 1991, 1996), which formed through a continuous accumulation of preserved fumier deposits. Accordingly, the eastern sector of the cave (CE) can be interpreted as corresponding area related to stabling and husbandry practices (Oms et al., 2008; Bergadà and Oms, 2021; Martín and Oms, 2021) (Fig. 4).

3. Materials and methods

The anthracological analysis of the Middle and Late Holocene archaeological layers at Cova Colomera is based on the study of 1117 charcoal fragments. A previous work consisted of the anthracological identification of 300 fragments from the EE1 silo (Oms et al., 2009b), but in the present study this assemblage is complemented with the identification of an additional 60 fragments. To recover the archaeobotanical remains, all the excavated sediment (from 2005 to 2011) was manually floated using bucket flotation, maintaining the spot height measurements (in 5 cm ranges) of the sedimentary facies and using a 0.2 mm mesh sieve.

Identification and quantification were performed according to the standard methodology used in anthracological studies (see Kabukcu and Chabal, 2021; Asouti and Kabukcu, 2021). The charcoal remains were quantified as the number of fragments per taxon and, to evaluate the optimal sample size of the layers, the accumulation curves were established (Chabal, 1997; Kabukcu and Chabal, 2021). The anthracological analysis was accomplished using reflected light microscopy, both bright- and dark-field (Olympus BX41), with magnifications of ×50, ×100, ×200 and ×500. The identification was based on anatomical features

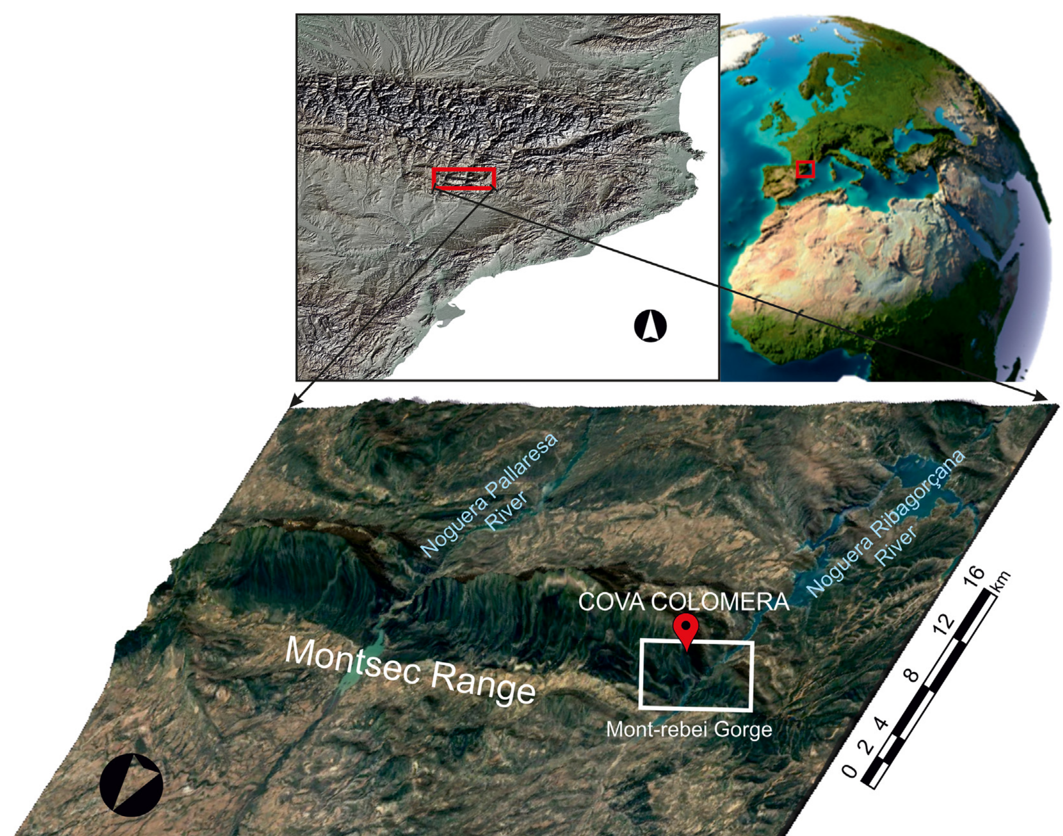

Fig. 3. 3D Location map of Cova Colomera, at N42°4′40.892″, E0°40′54.487″ (WGS 84).

Table 1
Compilation of published radiocarbon and calibrated dates from the Holocene sequence of the Cova Colomera test pit CE.

Layer	Type	Cultural attribution	Sample	Recovered	Radiocarbon	Ref. Lab	Date B.P.	cal yr B.C. 2σ	Cal yr B.P. 2σ	Published
CE8	*Fumier*	Middle Bronze age	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	OxA-23,633	3260 ± 26	1630–1470	3561–3400	Oms et al., 2015
CE8	*Fumier*	Middle Bronze age	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	Beta-140,550	3280 ± 40	1660–1440	3579–3395	Oms et al., 2015
EE1	Silo	Early Bronze age	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	OxA-17,732	3659 ± 30	2170–1930	4086–3896	Oms et al., 2009b
EE1	Silo	Early Bronze age	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	Beta-241,704	3630 ± 40	2130–1890	4084–3839	Oms et al., 2009b
CE9	*Fumier*	Late Neolithic	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	Beta-265,439	4230 ± 40	2960–2680	4863–4621	Oms et al., 2015
CE10	*Fumier*	Late Neolithic	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	OxA-17,331	4500 ± 32	3400–3040	5305–5041	Oms et al., 2015
CE12	*Fumier*	Early Neolithic	*Buxus sempervirens*	Manual flotation	AMS ^{14}C	Beta-248,523	6020 ± 50	5060–4780	7146–6737	Oms et al., 2013
CE13	*Fumier*	Early Neolithic	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	Beta-240,551	6150 ± 40	5250–4960	7164–6909	Oms et al., 2013
CE14	*Fumier*	Early Neolithic	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	OxA-23,634	6170 ± 30	5250–5010	7163–6964	Oms et al., 2013

described in the atlas of European woods compiled by Schweingruber (1990) and was supported by the reference collection of modern charcoal at the IPHES-CERCA (Institut Català de Paleoecologia Humana i Evolució Social), Tarragona (Spain). Unidentifiable charcoal fragments were assigned to broader categories based on their anatomical features. Undetermined fragments were classified as undetermined angiosperm or undetermined conifer. Fragments that retained some distinguishable anatomical feature, but did not allow attribution to species level, were numbered (e.g., indeterminate angiosperm 1). Anthracological analysis does not always allow charcoal fragments to be discriminated to species level (Chabal, 1992, 1997; Chabal et al., 1999), so in those cases other taxonomic groups were used (types, cf., or genera). Some specific taxa identified in the anthracological sample were regrouped (e.g., *Populus*/*Salix*; *P. sylvestris* type includes *P. sylvestris*/*nigra*; and *Quercus* sp. evergreen includes *Q. ilex* and *Quercus coccifera*) where the anatomical distinction between two or more species is not possible (Schweingruber, 1990). Undefined species ("sp.") of some genera were grouped together, such as *Acer* sp., *Fraxinus* sp., *Lonicera* sp., and *Juniperus* sp. Some species of the same genus have distinct specific anatomical criteria that may constitute different categories or types (Heinz and Barbaza, 1998; Alcolea, 2017; Allué et al., 2018a). Following Heinz and Barbaza (1998), for European woods from the Mediterranean basin, the genus *Prunus* can be classified into three types according to how many cells wide the rays are. The rays of *Prunus* type 1 (which includes *Prunus avium*/*padus*) are no more than two cells wide. The rays of *Prunus* type 2 (which includes *Prunus spinosa*/*mahaleb*) are three or four cells wide, and the rays of *Prunus* type 3 (which includes *P. spinosa*) are more than five cells wide. Finally, the family Rosaceae/Maloideae corresponds to several species, including, for example, *Sorbus* and *Crataegus*, which do not always share the same ecological adscription.

4. Results

The anthracological record from Cova Colomera incorporated 1117 charcoal fragments, of which 1038 were identified (Table 2A and B). Accumulation curves show an optimal sample size analysed in all layers (Fig. 5). The charcoal record shows a wide diversity of taxa, including broadleaves and lianas such as *Acer* sp. (maples), *Arbutus unedo* (strawberry tree), *B. sempervirens* (boxwood), *Clematis vitalba* (traveller's joy), *Corylus avellana* (common hazel), *Fagus sylvatica* (common beech),

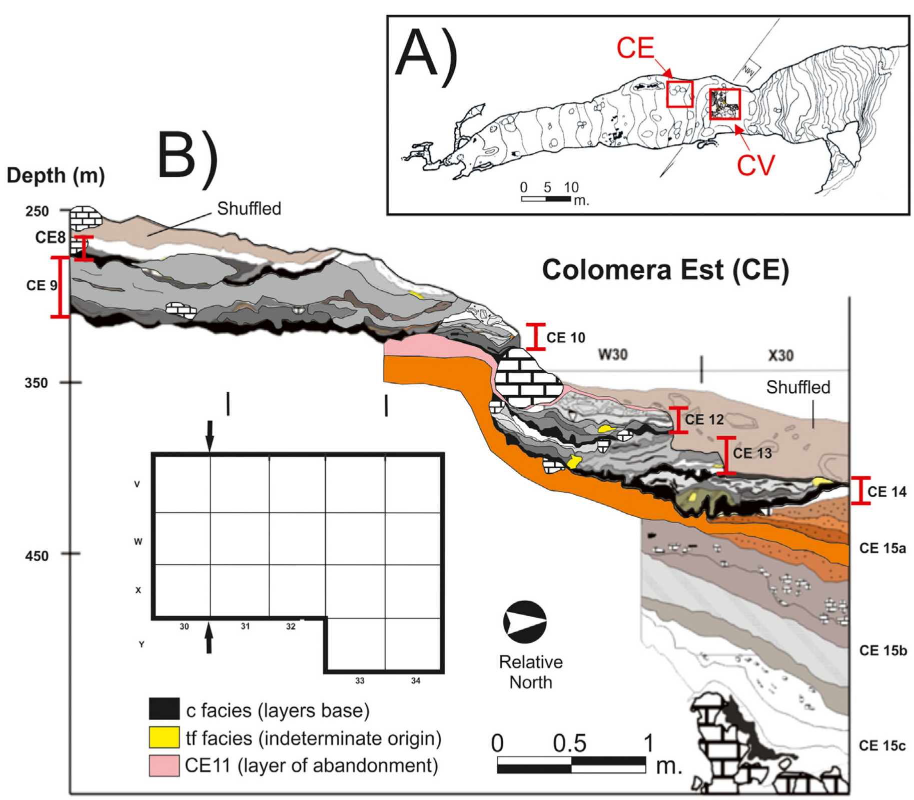

Fig. 4. A: Cave plan; B: Stratigraphic profile and grid-square (2008–2009) of the Cova Colomera test pit CE (Oms et al., 2013: modified). According to Angelucci and others (2009), *c facies* relates to the accumulations of charcoal fragments and *tf facies* refers to silt with abundant ash and varied colour, sometimes with platy structure and moderate cementation.

Table 2A
Middle Holocene anthracological record from Cova Colomera.

Archaeological period	Early Neolithic						Late Neolithic			
Layer	**CE12**		**CE13**		**CE14**		**CE9**		**CE10**	
TAXA	n	%	n	%	n	%	n	%	n	%
Acer sp.	9	7.50	11	7.33	17	8.42	24	7.12	14	14.00
Arbutus unedo	–	–	3	2.00	4	1.98	2	0.59	–	–
Buxus sempervirens	43	35.83	37	24.67	76	37.62	83	24.63	25	25.00
Clematis vitalba	–	–	–	–	–	–	1	0.30	–	–
Corylus avellana	–	–	1	0.67	–	–	1	0.30	–	–
Fraxinus sp.	–	–	–	–	–	–	4	1.19	–	–
Juniperus sp.	4	3.33	27	18.00	11	5.45	22	6.53	5	5.00
Lonicera sp.	–	–	–	–	–	–	–	–	1	1.00
Pinus sylvestris type	14	11.67	17	11.33	30	14.85	37	10.98	10	10.00
Pistacia lentiscus	–	–	1	0.67	–	–	1	0.30	–	–
Populus sp.	–	–	–	–	–	–	–	–	1	1.00
Prunus type 2	1	0.83	5	3.33	6	2.97	8	2.37	3	3.00
Prunus type 3	1	0.83	1	0.67	3	1.49	4	1.19	5	5.00
Quercus sp. *deciduous*	35	29.17	34	22.67	35	17.33	91	27.00	19	19.00
Quercus sp. *evergreen*	5	4.17	3	2.00	5	2.48	5	1.48	1	1.00
Rhamnus alaternus/Phillyrea	–	–	–	–	1	0.50	1	0.30	–	–
Rosaceae/Maloideae	–	–	1	0.67	1	0.50	–	–	–	–
Taxus baccata	2	1.67	–	–	2	0.99	18	5.34	6	6.00
Indeterminated angiosperm 1	–	–	–	–	–	–	–	–	1	1.00
cf. *Sambucus*	–	–	–	–	–	–	3	0.89	–	–
Total taxa	**9**		**12**		**12**		**16**		**12**	
cf. *Arbutus unedo*	–	–	–	–	–	–	3	0.89	–	–
cf. *Pinus*	–	–	–	–	–	–	1	0.30	1	1.00
cf. *Prunus*	–	–	–	–	1	0.50	–	–	–	–
Total identified	**114**		**141**		**192**		**309**		**92**	
Indeterminable angiosperm	6	5.00	6	4.00	6	2.97	18	5.34	6	6.00
Indeterminable conifer	–	–	–	–	2	0.99	–	–	–	–
Undetermined	–	–	3	2.00	2	0.99	10	2.97	2	2.00
Total sample	**120**	100	**150**	100	**202**	100	**337**	100	**100**	100

Fraxinus sp. (ash), *Hedera helix* (ivy), *Lonicera* sp. (honeysuckle), *Pistacia lentiscus* (lentisk), *Populus/Salix* (poplar/willows), *Prunus* type 2 and type 3 (plums), *Quercus* sp. evergreen and *Quercus* sp. deciduous (holm-oaks and oaks), *Rhamnus alaternus/Phillyrea* (buckthorn), Maloideae (pomes), indeterminate angiosperm and cf. *Sambucus* (elderberry), and conifers such as *P. sylvestris* type (Scots pine and black pine), *Taxus baccata* (yew) and *Juniperus* sp. (juniper). The taxon richness remains more or less homogeneous throughout the sequence, although taxon variability is higher in the Late Neolithic layers, especially in layer CE9.

The Early Neolithic layers CE12, CE13 and CE14 show a predominance of boxwood, with deciduous oak and *P. sylvestris* type subsequently. Maple shows low values in the three Early Neolithic layers (no more than 8.5%). On the other hand, juniper increases in layer CE13, although it displays a low presence in the earlier layer CE14. Sporadic fragments (≤5%), such as *A. unedo*, *C. avellana*, holm-oak, *P. lentiscus*, *Prunus* sp., *R. alaternus/Phillyrea*, Rosaceae/ Maloideae and *T. baccata* are present (Table 2A). By the same token, boxwood, deciduous oak and *P. sylvestris* type continued to predominate in the Late Neolithic layers CE9 and CE10. However, maple has higher recorded values compared to the previous period, detected mainly in layer CE10. Juniper shows a decrease. Other taxa, such as *Fraxinus* sp., *Lonicera* sp., *P. lentiscus*, *Populus/Salix*, *Prunus* sp., holm-oak, *R. alaternus/Phillyrea*, indeterminate angiosperm 1, *T. baccata* and cf. *Sambucus*, are also present. Likewise, *T. baccata* and *Prunus* sp. are documented in both these layers.

The Early Bronze Age silo EE1 shows high values for deciduous oak. Furthermore, boxwood and pine are well represented (Table 2B). Sporadic fragments of other taxa (≤5%), such as maple, ash, juniper and holm-oak, are also identified. Finally, the Middle Bronze Age layer CE8 is characterised by a predominance of deciduous oak and boxwood although, compared to the older layers, the values of boxwood are lower. Likewise, scarce appearances of *Acer* sp., *C. avellana*, *F. sylvatica*, *Fraxinus* sp., *H. helix*, *P. sylvestris* type, *Prunus* sp., evergreen oak, Rosaceae/Maloideae and *T. baccata* are identified.

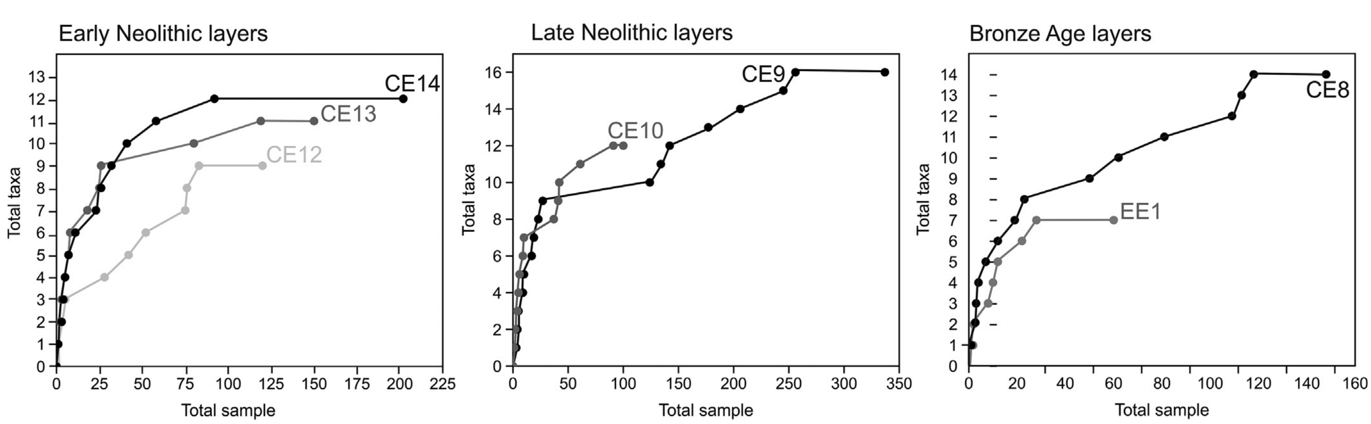

Fig. 5. Taxon accumulation curves of the Holocene layers of Cova Colomera.

Table 2B
Late Holocene anthracological record from Cova Colomera.

Archaeological period	Early Bronze Age			Middle Bronze Age	
Layer	**EE1**			**CE8**	
TAXA	n	Oms et al., 2009b	%	n	%
Acer sp.	2	23	6.94	11	7.43
Arbutus unedo	–	5	1.39	–	–
Buxus sempervirens	14	92	29.44	29	19.59
Corylus avellana	–	4	1.11	1	0.68
Fagus sylvatica	–	–	–	1	0.68
Fraxinus sp.	1	1	0.56	2	1.35
Hedera helix ssp.	–	2	0.56	1	0.68
Ilex aquifolium	–	4	1.11	–	–
Juniperus sp.	5	16	5.83	9	6.08
Pinus sylvestris type	14	25	10.83	9	6.08
Pistacia cf. *terebintus*	–	2	0.56	–	–
Prunus type 2	–	–	–	1	0.68
Quercus sp. *deciduous*	18	95	31.39	53	35.81
Quercus sp. *evergreen*	2	4	1.67	7	4.73
Rhamnus alaternus/Phillyrea	–	2	0.56	–	–
Rhamnus cathartica/saxatilis	–	3	0.83	–	–
Rosaceae/Maloideae	–	1	0.28	1	0.68
Taxus baccata	–	7	1.94	5	3.38
Tilia sp.	–	1	0.28	–	–
cf. *Ribes*	–	1	0.28	–	–
Total taxa	**18**			**13**	
cf. *Acer*	1	1	0.56	–	–
cf. *Corylus avellana*	–	–	–	1	0.68
cf. *Lonicera*	–	1	0.28	–	–
Pinus sp.	–	1	0.28	–	–
Prunus sp.	–	2	0.56	2	1.35
Quercus sp.	–	1	0.28	–	–
Rhamnus sp.	–	1	0.28	–	–
Total identified	**352**			**133**	
Indeterminable angiosperm	2	4	1.67	6	4.05
Indeterminable conifer	1	1	0.56	1	0.68
Undetermined	–	–	–	8	5.41
Total sample	**360**		100	**148**	100

5. Discussion

5.1. Transformation of the vegetation landscape and the environmental conditions around Cova Colomera

The anthracological results from Cova Colomera provide key data for describing the local-scale environment in the Central Pre-Pyrenees during the Middle-Late Holocene. Anthracological analysis of 1117 charcoal fragments from Cova Colomera shows the taxon diversity and changes in the relative values along the sequence (Fig. 6). Although the anthracological sequence is very homogeneous in terms of the richness and ubiquity of woody taxa, there is a tendency towards a progressive increase and predominance of deciduous forest elements. However, a slight increase in evergreen oaks is detected at the top of the anthracological sequence.

According to the anthracological results obtained, the local area of Cova Colomera remained relatively stable over the period in question, dominated as it was by forest communities of deciduous oaks, with a significant presence of *B. sempervirens* and *Acer* sp. This assemblage of taxa is usually associated with sub- and supra-Mediterranean deciduous oak formations. The presence of mesophilic taxa such as maple, *Prunus* sp., Maloideae, common buckthorn and boxwood can be taken to indicate temperate and humid climatic conditions. Other shrubby vegetation and small trees, such as *Juniperus* sp. and *R. alaternus/Phillyrea*, could have also developed in more open spaces, indicating the existence of clearances. These open forest formations under a humid climate may well correlate with the results from the study of the small vertebrates in the Holocene layers at Cova Colomera (López-García et al., 2010), which indicated the chorotype of micromammals with mid-European requirements, currently found at the higher altitudes of the Pyrenees. Sub-Mediterranean thermophilic elements requiring more humidity, such as *Tilia* and *Pistacia* cf. *terebinthus*, are identified in the silo EE1 at Cova Colomera, dated to the Early Bronze Age, and maple appears throughout the anthracological sequence. Riverine taxa, such as *Populus/Salix*, and *Fraxinus* sp., are documented, although their presence is always low. These elements are likely to have been part of the riparian vegetation, occupying the riverbanks in the Montsec mountain range or shadier and more humid locations such as deep narrow gorges. The other represented circum- and sub-Mediterranean small trees, shrubs and liana, such as *A. unedo*, *C. avellana*, *Ilex aquifolium*, *H. helix* and *C. vitalba*, appear in lower frequencies. The occurrence of *P. sylvestris* type suggests the presence of conifer forests, which underwent a slight decline in the course of the anthracological sequence, mainly during the Middle Bronze Age. These formations would have probably been growing at higher altitudes in nearby areas of the Pre-Pyrenees and *T. baccata* would have probably developed in shadier areas. In the other hand, holm-oaks and sclerophyllous elements such as *A. unedo* and *R. alaternus/Phillyrea* show a low relative frequency throughout the

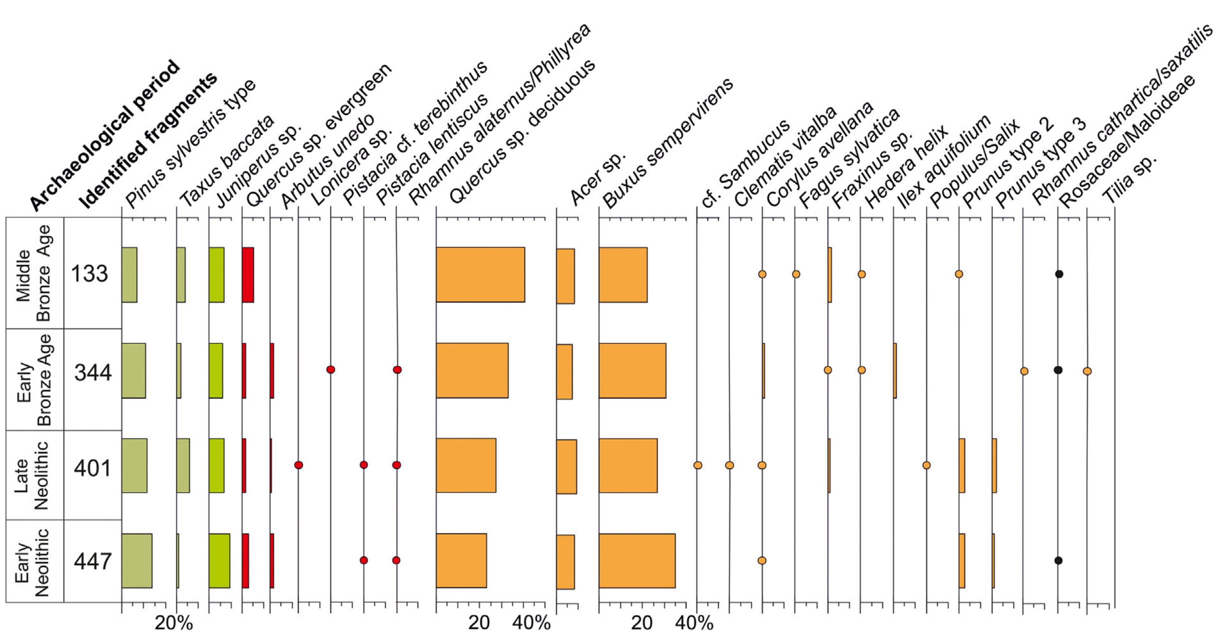

Fig. 6. Diagram with anthracological results for Cova Colomera. Results from Early Bronze age silo EE1 (Oms et al., 2009b) have been included.

anthracological sequence of Cova Colomera. However, from a diachronic point of view, a slight increase in holm-oak is detected, especially in the Middle Bronze Age.

In northeastern Spain and southern France, Mediterranean forests currently form an ecoregion in transition between the western European temperate broadleaf and mixed forest ecoregion and the Iberian sclerophyllous and semi-deciduous forest ecoregion (Dinerstein et al., 2017). Mediterranean forests thus display ecological characteristics of both the Mediterranean and Atlantic climate (Blanco et al., 1997; Carreras and Ferré, 2014). Likewise, the plant community that includes the evergreen oak forest and an evergreen understory of low trees and high shrubs (such as *Olea europaea*, *A. unedo*, *R. alaternus/Phillyrea*, *Erica* sp. and *P. lentiscus*) is also identified as an ecoregion of the Mediterranean biome that currently dominates the area. These sclerophyllous taxa display low representation throughout the anthracological sequence of Cova Colomera. They may have occupied secondary positions in drier or sunnier places, probably in areas of deciduous oak forest degradation.

In the Central Pre-Pyrenees, from the Early-Middle Holocene boundary (8.2 ka BP), the deciduous oak forest would have occupied a more extensive area than at present, favoured by a temperate and humid climate (Fig. 7). Palaeoclimate records from Pre-Pyrenean ranges, for example from Estanyá lake (Morellón et al., 2008), indicate greater water availability in three periods during the Holocene: the Early Holocene: 8.5–8.2 ka BP; and the Middle Holocene: 6.7–5.9 ka BP and 4.9–4.2 ka BP. Although these periods correspond to more humid conditions in the Mediterranean area, brief arid episodes also occurred at 8.2 and 7.5 ka BP (Jalut et al., 2009; Bergadà et al., 2018).

T. baccata records have very low values in pollen sequences, probably owing to the poor pollination rates and morphological difficulties (Chybicki and Oleksa, 2018), although the species is well represented in Middle Holocene anthracological records in the northern Iberian Peninsula (see Uzquiano et al., 2015), especially in mid-mountain areas. Differences in *T. baccata* values between anthracological and pollen data may correspond to variable humidity conditions at higher altitudes, which are probably dominated by coniferous forests. Additionally, the high relative frequency of boxwood in the Cova Colomera anthracological record is noteworthy. Boxwood is a sub-Mediterranean taxon, which currently grows in montane and subalpine zones and in some southern locations in the Iberian Peninsula, within an altitudinal range from 26 m to 2500 m a.s.l. (Bolòs and Vigo, 1984-2001; Carreras and Ferré, 2014). In some places, especially in disturbed oak forests, boxwood can play a pioneer role and can form extended shrubby formations, although it is most often associated with undergrowth in the

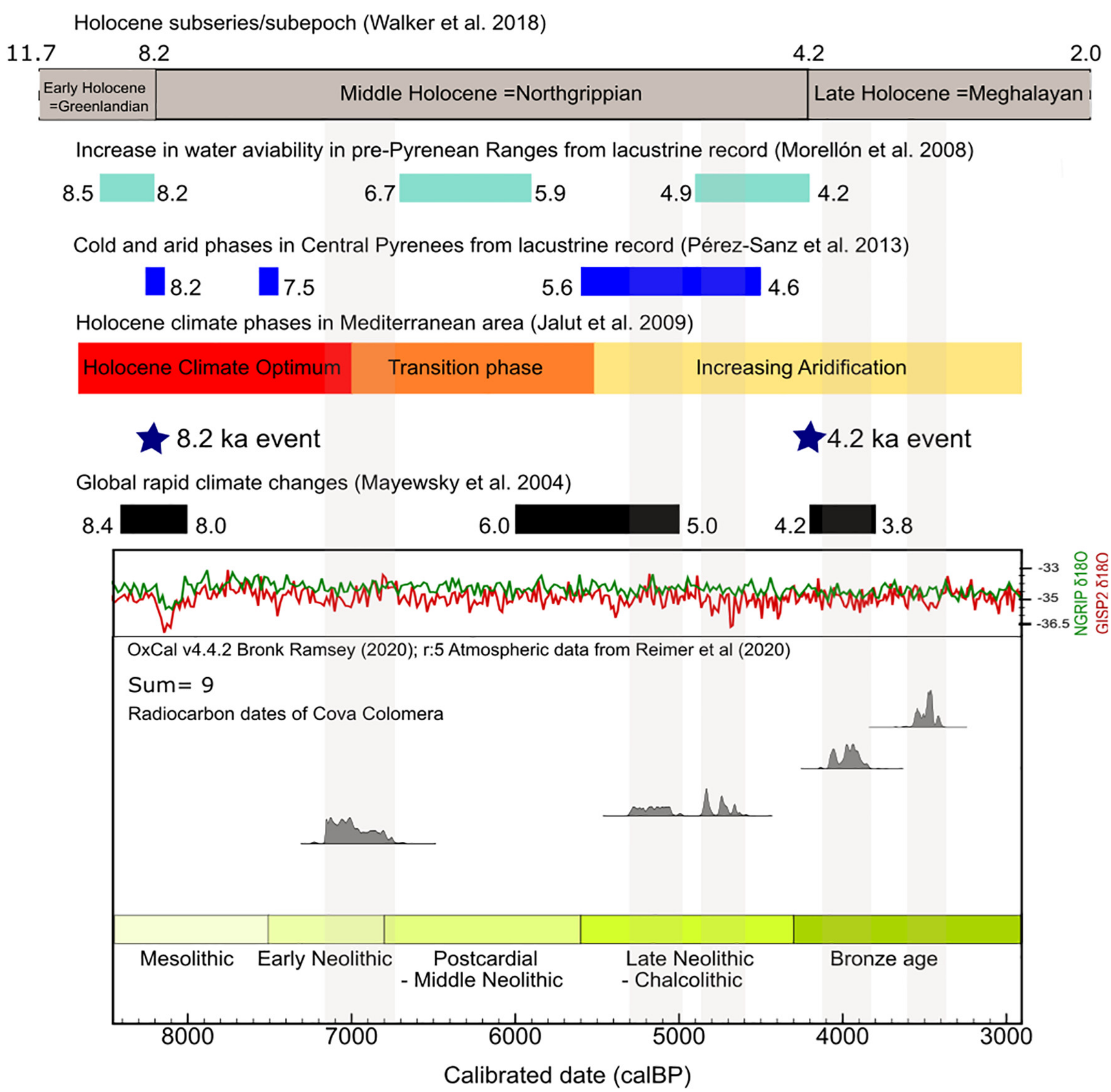

Fig. 7. Calibrated radiocarbon dates of Cova Colomera in relation of different climate proxies.

deciduous oak forest (Rivas-Martínez, 1987; Carreras et al., 2015; Pascual, 2015) and can be considered an indicator of degraded or cleared areas (Pascual, 2015). In the local area around Cova Colomera, woodland formed by deciduous oaks and including maple and boxwood is currently found as part of the forest structure, especially in more temperate or Eurosiberian areas in the Pyrenees and Pre-Pyrenees, under temperate and humid climate conditions. These taxa are common in Middle Holocene anthracological sequences from NE Iberian Peninsula, including littoral sites as well as sites in inner pre-littoral ranges, such as Cova del Toll (Mas and Allué, 2020), Cova de l'Avellaner (Ros, 1996), Cova Gran (Allué, unpublished), Cova d'en Pau III and Plansallosa (Ros, 1996; Piqué, 2005), La Draga (Piqué, 2005), Cova del Frare (Ros, 1996), Bauma del Serrat del Pont and La Prunera (Piqué, 2005).

According to our results, the dynamics of vegetation transformation during the Middle-Late Holocene were more or less homogeneous in the Central Pre-Pyrenees. On a local scale, global aridity events would not have affected the vegetation landscape structure, and deciduous oak forests, temperate taxa and montane conifers would have developed well in the area. The rapid global climate change detected in the 4.2 to 3.8 ka period (Mayewski et al., 2004) and the aridification trend that affected the Mediterranean basin (Fletcher and Sánchez Goñi, 2008; Allué et al., 2009; Jalut et al., 2009; Carrión et al., 2010b; Bergadà et al., 2018) may have been less influential than elsewhere in bringing about the Mediterraneanization of the Central Pre-Pyrenees landscape. Likewise, a slight increase in the evergreen oak forest was detected in the Middle Bronze Age layer of Cova Colomera. Yew, maple and boxwood continued to be well represented in Bronze Age layers from Cova Colomera and Cova Gran (Allué, unpublished). However, the vegetation composition deduced from these anthracological assemblages shows a continuing predominance of deciduous oak forests, with montane conifers and temperate taxa.

5.2. Anthropogenic impacts: Human and environment interactions

The archaeological record at Cova Colomera is associated with short-term occupations related to herding activities such as foddering, litter-bedding, etc. (Oms et al., 2013; Bergadà and Oms, 2021). The systematic burning of such fumier deposits often provides rich vegetal remains (see Angelucci et al., 2009; Euba et al., 2016; Vergès et al., 2016; Polo-Díaz et al., 2016; Burguet-Coca et al., 2020), and Cova Colomera is no exception. The anthracological sequence shows high taxonomic diversity, including 29 woody taxa. Some of these could have been part of the herd's fodder diet. However, we cannot rule out the use of some woody taxa as fuel, such as pine, juniper or yew, or as objects and tools that were thrown into the fire after use. Moreover, ovicaprine herds are a potential agent for reducing undergrowth vegetation. During the winter, browsing is focused on evergreen and semi-deciduous species, whereas in spring and autumn herbaceous grasses are also browsed (Bartolomé et al., 1998; Osoro et al., 2013). High-protein woody species such as *C. vitalba*, *Acer opalus*, *Quercus* sp., lentisk and strawberry tree are currently consumed by ovicaprine herds in Mediterranean areas (Rogosic et al., 2006; Bartolomé, 2014), whereas other taxa such as junipers and boxwood are rejected by herds as fodder (Bartolomé, 2014). However, the wood of the boxwood is also of good quality: hard, fine and compact, easy to polish and dye, and it could have been used for manufacturing objects. The wood produces slow combustion, a property much appreciated for its use as fuel (Caruso-Ferme and Piqué-Huerta, 2014). Examples such as the Neolithic settlement of La Draga (Banyoles, Girona) show the use of boxwood in the production of agricultural tools (Palomo et al., 2011; Piqué et al., 2018). Accordingly, archaeological work on some of the phases of the fumier documented the preservation and accumulation of leaves and branches of boxwood, possibly for the adaptation of beds or spaces for livestock (Bergadà and Oms, 2021; Oms et al., 2013).

Cova Colomera has provided no evidence of human occupation during the Middle Neolithic, although the cave was used by humans in the Early Neolithic and from the Late Neolithic to the Bronze Age cultural period. Two possible scenarios can be weighed up. In the NE of the Iberian Peninsula, evidence of occupation by Middle Neolithic populations has only been documented in burial contexts or in the open-air settlement of Ca n'Isach (Palau-saverdera, Girona) (Tarrús et al., 2016), whereas no evidence of occupation of caves and rock-shelters has been found (see Oms and Martín, 2018). A first hypothesis could be the non-preservation of evidence of human occupation due to erosion in karst systems and on mountainsides (see Polo-Díaz et al., 2014; Bergadà et al., 2018). A second, alternative hypothesis postulates the intentional abandonment of caves and rock-shelters due to changes in livestock grazing practices.

With respect to the human impact on forest communities at a local scale, the forest cover from the Early Neolithic to the Middle Bronze Age does not seem to have changed significantly in terms of either recovery or degradation. This could indicate that human groups carried out a reiterated but non-intensive exploitation of the forests. Accordingly, little evidence of intense human activities on the landscape can be found in the Iberian Central Pre-Pyrenees, although the exploitation of plant resources has been documented since the Upper Pleistocene and Early Holocene (Allué et al., 2012, 2018b). At lower altitudes and similar to Cova Colomera, Neolithic layers or structures at Les Auvelles (Oms et al., 2019), Cova Gran (Mora et al., 2011) and Forat de Conqueta (Mora et al., 2009; Allué, 2011) show similarities as well as slight differences in the composition of their vegetation landscape. On the one hand, the open-air archaeological site of Les Auvelles has yielded an anthracological record of oak taxa in which, although dominated by deciduous oak, evergreen oak is also represented, with high ubiquity values (Martín Seijo and Piqué Huerta, 2008). According to the authors, this assemblage could be influenced by specific fuel and wood selection patterns. On the other hand, anthracological data from the cave of Forat de Conqueta and the rock-shelter of Cova Gran (Allué, unpublished) indicate an assemblage similar to that of Cova Colomera. Archaeological research has identified livestock practices in the Holocene layers of Cova Gran, especially involving livestock enclosure, and has interpreted the use of the cave in terms of the transhumance routes through the southern Pyrenees (Polo-Díaz et al., 2014; Burguet-Coca et al., 2020; Martín and Oms, 2021), and also some mountainous Pyrenees areas (Gassiot et al., 2017; Knockaert et al., 2018; Tejedor-Rodríguez et al., 2021). The forest formations were probably the same in the different Pre-Pyrenean valleys, without any differences in human pressure causing more open forests in some areas.

Profound transformations of natural landscapes into cultural landscapes are currently the result of human pressure (Butzer, 1989; Quézel and Médail, 2003; Blondel, 2006; Pérez-Obiol et al., 2011). Humans have exploited forest wood resources and interfered with the natural development and distribution of woody plants for millennia. However, evidence of the anthropogenic footprint in the landscape during the Middle-Late Holocene is not homogeneous in the Iberian Peninsula. For example, it seems to be less intense in mountainous areas (e.g., Carrión et al., 2010b). In these areas above 2000 m a.s.l., Neolithic populations would have consumed varying amounts of wood according to the functionality and location of the settlements (Obea et al., 2021). Therefore, these archaeological sites show no evidence of extensive agriculture or substantial modification of the landscape. In contrast, the transformation of the vegetation landscape appears to be more intense in Mediterranean coastal areas (e.g., Riera-Mora and Esteban-Amat, 1994; Revelles et al., 2015). Nevertheless, there is no doubt that anthropogenic activities were important at a local scale particularly in the Late Holocene. The anthropic impact on landscapes during the Early Bronze Age has also been inferred from the increase in microcharcoal particles associated with the recurrence of fire events in mountain areas (Carrión et al., 2010b), more intensive land-use dynamics (Rull et al., 2021), and more specialised fuel-gathering patterns (Ros, 1995b, 1998; Piqué, 1999; Allué, 2007; Allué et al., 2009; Vila and Piqué, 2012; Obea et al., 2021).

6. Conclusions

The anthracological analysis of Cova Colomera documents changes in the vegetation landscape in the Central Pre-Pyrenees. These changes are related to specific climatic dynamics and a low anthropogenic impact, especially associated with herding and livestock management activities. The anthracological sequence shows how from the Middle to Late Holocene the local area of Cova Colomera continued to be dominated in the long term by deciduous oak forest ecosystems associated with sub- and supra-Mediterranean deciduous formations, while the coniferous forest gradually receded. According to our results, arid episodes in the Central Pre-Pyrenees did not cause major changes in vegetation cover, since the environmental conditions in the area of study included certain particularities that favoured the establishment of a temperate and humid climate. However, the Late Holocene began to show a slight increase in evergreen oaks, mainly during the Middle Bronze Age.

The evidence of the anthropogenic activities on the landscape during the Middle Holocene is not homogeneous in the NE Iberian Peninsula, as some areas displayed certain particularities. Neolithic human groups who settled in the open air and took advantage of the caves and rock-shelters to carry out specialised activities were well aware of the potential of the landscapes. However, the herding activities in evidence during the Neolithic seem to have exerted slight pressure on the structure of the different landscapes, especially in inland areas of the NE Iberian Peninsula such as the Central Pre-Pyrenees. The human presence in this area was therefore probably not intensive. Accordingly, we do not observe such intensive exploitation of forest resources as in the areas near the coast. Finally, the Bronze Age populations to which more intensive exploitation of forest resources is attributed on a regional scale do not seem to exert such an intensive influence at the local scale of Cova Colomera. The differences in the intensity of forest exploitation may be due to the different functionalities of the occupations as well as the different locations of the settlements.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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