Review of Palaeobotany and Palynology

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

--Manuscript Draft--

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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 1,117 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.
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Opposed Reviewers:	
Response to Reviewers:	We have corrected and reviewed all the reviewer's comments, and we have provided

	an answer or comment to each request. We sincerely believe that both reviewers have contributed to enrich our research. We would like to make some general comments. Firstly, about the quality of the pictures, we send all figures in high quality (TIFF format), although the quality seems poor in the generated pdf. In the other hand, we have modified the order of the discussion in section 4.2 and we have also improved the section 4.1, as the second reviewer suggested. Finally, we have improved the English idiomaticity throughout the manuscript, as a native Englishman has corrected the grammar mistakes and the style.

UNIVERSITAT DE BARCELONA

IPHES Institut Català de Paleoecologia Humana i Evolució Social

Tarragona, January 27th, 2022

Dear Editor,

We are submitting a revised version of the manuscript entitled "**Anthropogenic impacts on vegetation landscapes and environmental implications during the Middle-Late Holocene in the Iberian Central Pre-Pyrenees: an anthracological approach",** co-authored by Bàrbara Mas, F. Xavier Oms and Ethel Allué, for publication. The submission includes the manuscript, 2 tables and 7 figures.

We have corrected and reviewed the manuscript according to all the two reviewer's comments. We attach a document with all the answers and comments, the clean version of the manuscript, and the manuscript with control changes. We sincerely believe that the reviewer's suggestions have contributed to enriching our first draft. As reviewer 2 suggested, a native English speaker has corrected the English language of the manuscript. We have edited, also, Figures 1 and 6 and Table 2, and, finally, we have improved the Abstract and the highlights.

Hence, we consider this paper as appropriate for submission to the Review of Palaeobotany & Palynology

We hope you find our work suitable and interested for its publication

We look forward to hearing from you.

Sincerely,

Bàrbara Mas

We have corrected and reviewed all the reviewer's comments, and we have provided an answer or comment to each request. We sincerely believe that both reviewers have contributed to enrich our research. We would like to make some general comments.

Firstly, about the quality of the pictures, we send all figures in high quality (TIFF format), although the quality seems poor in the generated pdf. In the other hand, we have modified the order of the discussion in section 4.2 and we have also improved the section 4.1, as the second reviewer suggested. Finally, we have improved the English idiomaticity throughout the manuscript, as a native Englishman has corrected the grammar mistakes and the style.

Reviewer comments:

Reviewer #1: The paper submitted by Bàrbara Mas and co-authors to Review of Palaeobotany and Palynology presents new anthracological data that show regional forest transformations in the Central Pre-Pyrenees (Iberian Peninsula) during the Middle to Late Holocene. The study provides a complete anthracological sequence at Cova Colomera (Mont-rebei Gorge, Central Pre-Pyrenees). This paper is a very nice illustration of the interest of palaeobotany to contribute to the development of such scientific themes. This impressive contribution will be very appreciated by the scientific community, among them researchers working on Holocene. The paper fit well with the standards of Review of Palaeobotany and Palynology. The text is well organized, very easy to read and the topic is clearly developed. Therefore, I strongly recommended publication in RPP with only minor revisions.

I suggest only a few minor changes:

Line 31: Replace semicolon by coma after 2007.

Done

Line 193: Write in italics Acer, Fraxinus, Juniperus and Prunus.

Ok. Probably, a M.Word's mistake.

Line 200: Write in italics Sorbus and Crataegus.

Done. Probably, a M.Word's mistake

Line 204: Use the same criteria with the numbers, or dot or coma. See 1.117 and 1,038.

Done, thanks!

Line 357: Add coma after Médail.

Done.

Line 362: Delete dot after m a.s.l.

Done.

FIGURES AND TABLES

Figure 6 and Table 2. Write the first p of Phillyrea in capital letters. Done.

Reviewer #2: General comments

The title is very ambitious. Consider adapting it to the data presented in this study. The data is mainly from one cave site, Cave Colomera that was discontinuously used from the Early Neolithic to the Middle Bronze Age. The anthracological information from the cave is not integrated in a comprehensive manner with other anthracological data from the area in order to present what the title implies. Some sites are mentioned throughout the text but in a rather random manner. Sites with relevant data are pointed in figure 1 but they are not mentioned in the caption. Neither are their anthracological data synthesized in the text so that to create an anthracological record for the area in order to discuss anthropogenic impact and vegetation change.

The discussion is in general difficult to follow. I suggest a reorganization based on
1. Clear presentation of the anthracological characteristics of Cave Colomera, vegetation types, specific importance of certain taxa, interpretation of the anthracological diagram
2. Synthesis of other anthracological data from the area that show differences/similarities through time between hinterland and coastal areas
3. Broader climate changes of the Holocene and how can these be correlated to the anthracological data from archaeological sequences. This part is challenging and should be touched upon with caution, due to the discontinuity of the archaeological record
4. Anthropogenic involvement: Firstly it is necessary to discuss the case of the cave, what uses of the vegetation, how continuous or discontinuous these were and what does the anthracological data reveal for the local area. In continuation the broader area can be discussed making a clear differentiation between cave sites for animal penning and other open air sites.

In the conclusions some issues appear rather controversial, maybe it is a matter of the use of the English language (see next)

It is necessary that a native English speaker corrects and does the editing of the manuscript

For the references and citations: in general when there are 2 surnames in the references they should both be used in the citations in the text

We have made changes in the discussion according to the suggestions of the reviewer, this has helped to clarify the organization on the different subjects we are discussing. Although the discontinuity of the sequence, Cova Colomera is one of the most complete in the area recorded to date. We consider that although this paper focus on Cova Colomera offers a broader perspective on the analyses considering the title according to the content. In this aspect, the bias of Middle Neolithic data and the evidence of shorts occupations have been included in the discussion. We have edited the English of the manuscript to correct and clarify some misleading sentences in the discussion.

Abstract

In the first paragraph:

"The anthropogenic footprint" would be the result; Maybe the authors mean human activities?

Yes, we have changed it.

In the abstract it should be specified the time range of the study, Middle and Late Holocene is too long. Please specify at least which millennia after Early, Late Neolithic, Early, Middle Bronze Age. Transformation in landscape changes? not understandable In the second paragraph: Subsequently to what? In the part of the paragraph before subsequently specify to what period you refer to. In some specific places? This is too vague, please clarify what you mean

We have improved this section according with the suggestions.

In the main text

Line 18: Late instead of late

Done.

Line 23 to 25: The whole sentence needs to be changed and corrected

Done.

Line 27: several proxies, mainly pollen and charcoal? Which 3ret he proxies?

We have revised and changed the sentence.

Line 29: give time range for the Early Holocene

Done.

Line 34: give time range for Middle Holocene

Done.

Line 42: fumiers are related to human activities such as stabling animals? I think it is the result of stabling animals. What other activities could be involved?

You are right. The expression was probably inaccurate. We have corrected it

Line 50: Chabal 1999 does not exist in references, maybe Chabal et al 1999 or Chabal 1997

Done. Chabal et al., 1999.

Line 51: Kabukcu and Chabal 2021 not 2020, change also in references

Done.

Line 57: local dynamics could be relevant. Can you please explain what you mean in relation to the diversity at a regional scale?

Done. We have changed the sentence.

Line 62: because of the possibility of connecting near sites? Check English

Done.

Line 66: from Early Neolithic to middle Bronze Age: give time ranges at least in millennia

Done,

Lines 68-70: assess the impact of what? vegetation change? Its causes? It is not clear to me what the sentence means

Done. We have changed the sentence and included more details.

Lines 92-93: The northern slope of the range, the Tremp-Graus basin,

Better, thanks!

Line 96: in a local area? Locally?

We have corrected it.

Lines 99-105: I think the vegetation of the Ager area should go directly after the description of that part of the range. That would directly facilitate comparison

We agree. Done.

Line 101: the area is located in biome? Maybe better "The biome of the area…."

It's better, thanks

Line 103: in a local area? Locally?

Done.

Line 117: a gallery? Maybe the authors mean a chamber?

Done, it was a translation mistake.

Line 137: a narrow concentration? Is it a layer? Maybe the authors mean a thin layer/concentration?

We have improved the sentence.

Line 139: part of their diet? You mean leaf fodder? And also how do you know this is a Holocene layer? Which layer is it? Is there a date? What is the material culture?

Done. We have improved the sentence.

Line 144: Veraza and Veraza-Ferrières cultures. Not all readers are familiar with local /regional sequences. Can you provide chronologies for these cultures?

Table 1 shows the dates of archaeological layers. These two cultures constitute two horizons of ceramic assemblages. As this article does not discuss ceramics, reference is made to paper that includes the ceramic material.

Line 160: why is it 3.1? there is no 3.2, please change

It's true. Thanks!

Line 163: a previous work

Done.

Lines 164-166: the results from both studies should be included in Table 2. There should be correlation between what is written here, what is shown in the diagram (Figure 6) and what is included in table 2

You are right. We have included the analysis of 300 samples from silo EE1 (Oms et al., 2009) in Table 2.

Line 168: maintaining the arrangement of the facies (Z-Z1)? What does this mean? Please explain. Also in the same line place the mesh size together with the flotation method used

Done, we have changed and improved the sentence.

Line 169: why is it mentioned here the method for the small-mammal remains? irrelevant? Or maybe more wood charcoal was collected from those samples? Please clarify and organize

We have clarified the reference.

Line 174: are they saturation curves? See Kabukcu and Chabal 2021. Why were they established? Later on they are used to refer to the taxonomic variability of layers. Is this why they are used for in anthracology? See also below comment for figure 5

We have clarified the reference. It was a language translation mistake.

Line 176: analysis

Done.

Lines 186 to the end of section: check English language and clarify what taxa you define. What does "are regrouped in terms of species" "mean?

We have clarified this section.

Line 193, 197 and 200: Acer, Juniperus, Fraxinus, Prunus, sorbus, Crataegus not bold but Italics

Done,

Line 199: but for the discrimination between Amygdalus and Prunus spinosa see the criteria established in Scweingruber 1990, 643

Yes, we have deleted Amygdalus in our assemblage because we have not observed ring-porus wood character in *Prunus* samples. However, we have followed your recommendation and the description of Prunus type has been improved.

Line 199: Rosaceae/Maloideae not capital

Done.

RESULTS

Line 204: 1117 recovered? Maybe 1117 studied and 1038 identified

Done.

Line 205: 22 woody species? Here and throughout the text replace species by taxa. Not all identified material corresponds to species

Done.

Line 206: of the current sub-Mediterranen climatic type. I think this is interpretation and it should go in the discussion where it should be integrated in the description of the conditions in the study area in the past relative to the presence of the identified taxa

We have clarified the sentence.

Line 206: what is ubiquity of frequency? There is no ubiquity analysis of the taxa in this study

We have clarified the sentence.

Line 209: The curves in Figure 5 were obtained to show taxa richness in different layers? What is the purpose of accumulation curves?

To explain the anthracological assemblage richness of Cova Colomera. In the discussion, the diversity of taxa is explained.

Lines 213-218: this is inaccurate, the woody taxa listed are deciduous and evergreen and to my knowledge Fagus sylvatica is neither thermo nor meso-Mediterranean

It’s true. Done.

Line 218: Rosaceae/Maloideae

Done. ,

Line 222 and 224: shrubby is interpretation. How can it be known that these small trees had a shrubby form? And how can it be known that junipers were shrubby and not tree-like?

You are right. We have changed these lines.

Lines 232-235: Other taxa….. not continuously". If the sentence describes the presence of taxa in one layer and this is what is shown in Table 2 how can "continuity" be perceived. This could only be possible through comparison of consecutive layers

It was an editingmistake. We have changed it.

Line 237-238: Please explain in the caption what the curves show in relation to the results and the anthracological method in general? Or otherwise clarify in the methods section

Done.

Line 244: boxwood

Done.

DISCUSSION .1.

Line 269: is Arbutus sub-Mediterranean?

We have changed it with “circum-Mediterranean”.

Line 276: Why is it holm oak here and elsewhere evergreen Quercus? Also which are the associate elements? They should be named. And shouldn't there be Arbutus and Rhamnus/Phillyrea among them?

We have clarified and improved it.

Lines 280-289: what are Mediterranean forests? All information about Mediterranean, sub-mediterraenan and Atlantic should be explained. However, it would be preferable to make all the necessary comparisons in relation to what is depicted in figure 2. I believe it serves better the purposes of the manuscript than other general descriptions. All the section needs thorough revision. Which are the taxa typical of the Holm oak forest? In cases the same taxa appear as deciduous, sclerophyllous (i.e. Arbutus) sub-mediterranean, or Mediterranean.

We have improved this section.

Line 289: what are percentages of ubiquity value? Relative frequency of fragment counts per layer/per period are presented in Table 2 and figure 5

We have clarified the sentence.

Line 290: what is a secondary position?

We have clarified and improved this section.

Lines 292-294: What are the results from the study of small vertebrates. If it is mentioned it should be explained to show how it supports the anthracological results

We have improved this explanation.

Line 305: starting with "however" it should correlate with something. What is it? Is it something about the changes of the Late Holocene seen through other proxies? If so these should be described first and then make the comparison with the Bronze Age at Cave Colomera

We have reorganized and improved this section.

Line 316: what ubiquity values and in comparison to what? Other antrhacological results from Iberia?

Translation Language mistake. Done and clarified.

Line 305-335: Revise and organize the data so that they are meaningful

We have reorganized and improved this section.

Line 337: how can you discuss about the 8.2 event? It is not represented in your sequence

We have not discussed the 8.2 event. We have only used it as a starting point for explaining the Middle-Holocene scenario.

Line 338-339: this is not seen in the anthracological sequence. Which are the xerophilous shrubs that start to expand? Arbutus, Pistacia, Phillyrea are not present, Quercus evergreen increases slightly. Contrary to that Quercus deciduous shows increasing trend throughout

We have reorganized, clarified and improved this section.

DISCUSSION .2.

Line 361: specify in which period of the Middle Holocene you refer because later on you compare with the Early Bronze Age (line 367).

Done. We were referring to the Middle-Late Holocene.

Line 362-364: I do not understand the comment. What is wood consumption? Fuel? Timber? And are these the only means that may affect the vegetation of an area? What about animal herding, forest fires for pasture, woodland management for leaf fodder, etc. Please explain what you mean.

We have improved this section,

Line 370: Ros 1995 a or b

Thanks, is 1995b

Line 391-392: How does this observation correlate with the uses of wood distinguished through the antrhacological study?

Several of the taxa identified are recurrent in ovicaprine diets. This point has already been discussed.

Line 399: what wood? of juniperus and boxwood?

Thanks for the observation, is boxwood. Done.

Line 408-409: from the Early Neolithic to the Middle Bronze Age

Done

From 408 to the end the information relates to the characteristics of the broader area but this is not clearly structured. From the specific uses of the taxa at Cave Colomera the focus turns to vegetation dynamics from the Middle to the Late Holocene in the Pre-Pyrenees without a clear definition of what has to be compared.

We have improved this section. We compare, from a local point of view, the dynamics of vegetation with the low impact of human activities.

Line 411: how permanent is defined? Can the anthracological data show that? How could the exploitation be permanent if the archaeology of the caves shows long periods of no use?

This is a translation mistake, we were referring to reiterated or recurrent exploitation.

Line 419: mixed oak taxa?

We changed this sentence for oak taxa.

Line 427: Diaz Polo et al. 2014?

Done.

Line 430: "with any differences"? Maybe "with no differences"

Done

Line 440: the retreat of conifers only briefly mentioned in the discussion

We have improved this question,

Line 444-445: at the local scale of Cave Colomera the expansion of xerophytic shrubs and Quercus is not obvious

True, we have improved this sentence.

Line 451-452: to conclude: is there evidence of some pressure in inland areas in the Neolithic? How should "incipient pressure" be understood? "No pressure" or "the beginning of pressure"? I understand the second but in the discussion the arguments are against it

We have improved this sentence.

Line 456: what is the specialized selection pattern of forest resources? How is it justified in the discussion? An in particular about herding at Cave Colomera?

We have improved this sentence.

References
Allue 2009, not found in references

Badal 1999, not found in references

Both references are et al. Thanks for your observation. We have corrected the reference in text.

Figures – Tables

Figure 1: consider using subepoch without hyphenation as in Walker et al. 2019, Journal of Quaternary Science 34(3): 173-186 https://doi.org/10.1002/jqs.3097you In the caption the names of the sites should be mentioned and correlated with the numbers. If no mention to the sites is made what is the point of numbering them? Some sites are mentioned in the text and it would be useful to see which and where they are located. Also, the time range of the Middle and Late Holocene is long. To which part of the Late Holocene do the sites correspond. Consider adapting the caption of figure 1 to include all this information e.g. for the Lower Holocene the sites correspond only to the 2nd millennium BC

We have modified the figure and included the name of the sites, reference and archaeological period in the caption.

Figure 2: The quality is not good, but I am not sure if this is due to low resolution conversion for the pdf file. It should be very clear and probably used to make comparisons instead of using other general information (see also comment for lines 280-289)

The poor quality is due to the generation of the pdf. All figures in this paper were sent in tiff format and at high resolution.

Figure 4: Please explain in the caption what is c facies (layers base) = layers base

of what? Of fumier? tf facies (indeterminate origin) = indeterminate origin relative to what?

These acronyms correspond to the excavation methodology of a fumier, and identify the origin and composition of different layers, according to the study by Angelucci and others (2009). Given the confusion that this can generate, we have improved the caption of the figure.

Figure 5: explain what does it show? Is it a saturation curve or an accumulation curve? See the discussion in Kabukcu and Chabal 2021, 12-13

We have improved this section.

Figure 6: The first column from left should be Cultural Period instead of Age. In Table 2 it is Archaeological Period

Done, we changed as Archaeological Period.

Second column from left should be Identified fragments, what is determinated?

Agree. We have changed for Identified fragments.

For the Early Neolithic the total identified fragments in Table 2 are 447. Why 446 in Figure 6?

Done, the correct are 447.

For the Late Neolithic the total identified in Table 2 are 401. Why 402 in figure 6?

Done, the correct are 401.

For the Early Bronze Age there is a huge difference in total identified between Table 2 (57) and figure 6 (344)

In Table 2 only the results of the new anthracological analysis were included, while in the diagram in figure 6 the published results of silo EE1 (Oms et al, 2009) were included. We agree with your comments and have included in Table 2 the results of Oms et al, (2009).

Phillyrea with P capital.

Done

Add sp. to Tilia?

It’s true! Done

Hedera helix ssp?

We have changed to *Hedera helix*

What is the significance of the colours? It should be explained. As I understand it the red are the thermophilous ones and the orange the more temperate? But is it really like that for Tilia (red) and Arbutus (orange)?

Done.

Figure 7. Nice synthetic figure but poor quality

The poor quality is due to the generation of the pdf.

Table 2. Capital P for Phillyrea. Why ROSACEAE/MALOIDEAE in capital? Please change

Done.

Change determined with identified

Agree. Done.

Have the % been calculated based on the totals? I believe they should be calculated on the basis of the total identified (cf. Chabal 1997)
In the caption of Table 2: what does "Absolute (n) and relative frequencies (%) of charcoals fragments analyzed with species recorded."? Do the author(s) mean "Absolute and relative frequencies of taxa based on fragment counts"
An as elsewhere, species should be replaced by taxa

We have changed and improved the caption.

Anthropogenic impacts in vegetal landscapes and environmental implications during the Middle-Llate Holocene in the Iberian Central Pre-Pyrenees: an anthracological approach

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Keywords

Landscape transformations; Anthracology; Cova Colomera; Middle-Llate Holocene; Northeastern Iberian Peninsula

1. Introduction

The impact of general Holocene climate dynamics was unequal in past Mediterranean landscapes. Mainly in the first stages of the Holocene (11.7 ka years BP to 4.2 ka years BP), the influence of climatic agents on landscape transformation was more evident than the impact of human activities. However, since the Middle-Late Holocene Boundary (4.2 ka years BP), discerning which of the two agents, natural factors or the anthropogenic footprint, was the main contributor to landscape transformation, or whether it was a combination of both, is controversial or less obvious ~~Mainly, from the Early Holocene, natural changes in landscapes and a period of predominantly anthropogenic change are difficult to discern until the Late Holocene~~ (see Jalut et al., 2000; Roberts et al., 2011). ~~Past~~ Holocene Mediterranean ~~vegetation~~ woodland history and landscapes changes ~~landscapes and their transformation during the Holocene~~ have been studied using a ~~several proxies~~palaeoecological proxy, mainly pollen and charcoal data (~~see~~ e.g. Jalut et al., 2009; Woodbridge et al., 2018; Roberts et al., 2019; Picornell-Gelabert et al., 2020)~~, mainly pollen and charcoal data~~. 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). ~~Subsequently~~Further, during the Middle Holocene sub-epoch (8.2 ka years BP to 4.2 ka years BP), warmer and more humid climatic conditions prevailed as precipitation regimes increased, favoring 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-Sampéritz et al., 2017). Simultaneously, from the Early Holocene, Neolithisation throughout the Mediterranean involved agricultural expansion 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 to the Iron Age (see Angelucci et al., 2009). Fumiers are the result of ~~human activities, such as~~ 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 the accumulation of animal dung. Plant material in this type of deposit has different origins related to such human practices as foddering, animal beds, fuel, refuse or fencing (Brochier, 1983, 1991, 1996; Polo-Díaz et al., 2014, 2016; Burguet-Coca et al., 2020).

Anthracology, besides being an important proxy for detecting different past local landscapes, 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~~0; Asouti and Kabukcu, 2021~~). Anthracological data available for the NE Iberian Peninsula during the Middle Holocene and the Late Holocene sub-epochs (i.e. Senabre and Socias, 1993; Heinz and Vernet, 1995; ~~-~~Ros, 1995a, 1995b; 1996, 1998; Piqué, 1999, 2005; Allué, 2007, 2010; Martín and Piqué, 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~~, and~~ a~~s~~ consequence, research based on a local approach may be relevant to reconstructing the regional variability~~local dynamics could be relevant~~ (Figure 1).

PLACE HERE FIGURE 1. ~~Location of Cova Colomera and archaeological~~Archaeological sites with available Middle-Late Holocene anthracological data ~~in the~~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;

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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., 2015); 19) Bauma Margineda (Heinz, 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 and Piqué, 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).

The C~~c~~entral Pre-Pyrenees (southern Pyrenees, Iberian Peninsula) is remarkable for ~~its evidence of herding~~herding's evidence activities~~ in the NE Iberian Peninsula~~, as documented at Cova Colomera (see Bergadà and Oms, 2021; Martín and Oms, 2021), and also ~~because of the possibility of connecting near~~in other archaeological sites with available anthracological data (i.e. Polo-Díaz et al., 2016; Burguet-Coca et al., 2020). 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 BC to 3th millennium cal BC), has focused on a diachronic perspective in order to understand the role of anthropogenic

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activities and climate change in the transformation of local environments and shaping the cultural landscape. Therefore, the main objectives are to understand vegetation change and its causes, and thus to estimate the impact that the Neolithisation process may have had on vegetation landscapes.Therefore, the main goals are to comprehend vegetation change and its causes, and thus assess its impact on landscapes during the Neolithisation process.

1.1. Geographical area and landscapes

The study area is located in the Montsec range, in the Central Pre-Pyrenees (southern Pyrenees, Iberian Peninsula), between the Tremp-Gaus 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 topography is the result of a series of monoclinal mountain ranges along 40 km, in an area of 186.96 km^2, oriented from west to east. Three rivers, Boix River, Noguera Pallaresa River and Noguera Ribagorçana River, cut through the ridge from north to south. When crossing the Montsec range, these water courses have eroded and shaped narrow gorges and routes, like 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.) and loses height towards its ends.

The southern slope of the range, the Ager Basin, is characterized by longer summer drought and, therefore, drier climate conditions. Ager basinLocally, the area is under the influence of a sub-Mediterranean climate type, although 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, while 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 with mean precipitations of around 40 mm) and a minimum in summer (July with precipitations of less than 13 mm). The mean annual temperature oscillates between 11 and 13ºC, with a maximum of 31ºC in July and a minimum of 0ºC in January (Meteocat data 2020 from Camarasa municipality) (Figure 2). The biome of the area is characterized by Mediterranean forests, woodlands and scrub, which belongs to the Iberian sclerophyllous and semi-deciduous forests (Dinerstein et al., 2017). In a local area, holm-oak forests (*Quercus ilex* subsp. *ilex*) and Aleppo pine forests (*Pinus halepensis*) expand

The northern slope of the range, (Tremp-Graus Basin,) is rainier and shadier, and consequently the climate is more temperate and could present a Eurosiberian trend. The biome is characterized by a temperate broadleaf and mixed forest, which belongs to the Pyrenees conifer and mixed forest ecoregion (Dinerstein et al., 2017). In a local areaLocally, beech forest and oak forests are predominant (*Quercus faginea, Quercus cerroides* 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. *salzmanii* and *Pinus sylvestris*). However, the southern slope of the range (Ager Basin) is characterized by longer summer drought and, therefore, drier climate conditions. The area is located in a biome characterized by Mediterranean forests, woodlands and scrub, which belongs to the Iberian sclerophyllous and semi-deciduous forests (Dinerstein et al., 2017). In a local area, holm-oak forests (*Quercus ilex* subsp. *ilex*) and Aleppo pine forests (*Pinus halepensis*) expand.

PLACE HERE FIGURE 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?).

2. Cova Colomera cave

Cova Colomera is located in the Mont-rebei gorge, Serra del Montsec (Central Pre-Pyrenees, NE Iberian Peninsula). The cave is located 670 m 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) (Figure 3). The cave entrance is 70 m high and 30 m wide, and leads to a ~~gallery~~ chamber about 180 m long and 10-12 m wide (Oms et al., 2013).

PLACE HERE FIGURE 3. 3D Location map of Cova Colomera, at N42º4'40.892", E0º40'54.487" (WGS 84).

From 2005 to 2011, an interdisciplinary team from the Seminari d'Estudis i Recerques Prehistòriques (SERP-UB) excavated the cave, allowing the description of the stratigraphic sequence (Oms et al., 2015). Two 26 m^2 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 and one Late Pleistocene archaeological layers ~~and a Late Pleistocene one~~ were registered in CE test pit (Table 1).

PLACE HERE TABLE 1. Compilation of published radiocarbon and calibrated dates from the Holocene sequence ~~in~~ of the Cova Colomera test pit CE.

Lower unit CE15 (CE15a, b and c), corresponding to the Pleistocene, was not anthropic in origin, but many micro- and macrofauna 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 ~~narrow concentration~~thin concentration of boxwood leaves and white-colored branches, that corresponds to Holocene's top unit, layer CE14 (7163-6964 cal. years BP). ~~Plant~~ Boxwood remains, such as branches and leaves, were documented in a primary position, which have been interpreted as a bed for the herd or part of their diet (i.e. Oms et al., 2013; Bergadà and Oms, 2021). Layers CE14~~ (7163-6964 cal. years BP)~~, 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, the layer CE8 (3579-3395 cal. years BP, 3561-3400 cal. years BP) corresponds to the Middle Bronze Age. All Holocene layers correspond to an *in-situ* sedimentary facies of fumier type (*sensu* Brochier, 1983, 1991, 1996), which formed by a continuous accumulation of preserved fumier deposits. Therefore, the eastern sector of the cave (CE) would correspond to an area related to herd stabling and husbandry practices (Oms et al., 2008; Bergadà and Oms, 2021; Martín and Oms, 2021) (Figure 4).

PLACE HERE FIGURE 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 color, sometimes with platy structure and moderate cementation.

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3. Materials and methods

~~**3.1. Anthracological analysis**~~

Anthracological analysis of Middle and Late Holocene archaeological layers at Cova Colomera is based on the study of 1.117 charcoal fragments. A previous~~ly~~ work consisted of the anthracological identification of 300 fragments from EE1 silo (Oms et al., 2009b), but in the present study, this assemblage has been completed 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 heights~~arrangement~~ measurements (in 5 cm ranges~~Z-Z_1~~) of the sedimentary facies, and using a 0.2 mm mesh sieve.~~ To recover the small mammal remains, the sediment was water sieved with two superimposed meshes of 5 and 0.5 mm (García-López et al., 2010).~~

Identification and quantification were performed according to the standard methodology used in anthracological studies (see Kabukcu and Chabal, 2021~~0~~; Asouti and Kabukcu, 2021). The charcoal remains have been quantified in 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)~~to evaluate the homogeneity of the sample, and taxonomic saturation curves were established (Chabal, 1997)~~. Anthracological analysi~~e~~s was accomplished using reflected light microscopy, both light- and dark-field (Olympus BX41) with magnifications of x50, x100, x200 and x500. The identification was based on anatomical features described in the atlas of European woods (Schweingruber, 1990) and was supported by the reference collection of modern charcoal at the IPHES (Institut Català de Paleoecologia Humana i Evolució Social), Tarragona (Spain). The 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), and therefore in those cases other taxonomic groups were used (types, cf., genera or species). These specific taxa identified in the anthracological sample were regrouped (e.g., *Populus/Salix*; *Pinus sylvestris* type includes *Pinus sylvestris/nigra*; and *Quercus* sp. evergreen includes *Quercus ilex* and *Q. coccifera*), since the anatomical distinction between two or more species is not possible (Schweingruber, 1990). ~~Some genera, such as *Acer*, *Fraxinus*, *Juniperus* and *Prunus* only occasionally display differences in specific anatomical criteria, therefore~~ Undefined species "sp" of some genera have been grouped, such as *Acer* sp., *Fraxinus* sp., Lonicera sp., and *Juniperus* sp.~~are regrouped in terms of species "sp", usually accepted by anthracological researchers~~Some species of

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the same genus have distinct specific anatomical criteria that may constitute different categories or types. ~~. Some of the characters allow certain species to be regrouped into different types~~ (Heinz and Barbaza 1998; Alcolea, 2017; Allué et al., 2018a). Based on Heinz and Barbaza (1998), for European woods from the Mediterranean basin, the genus~~era~~ *Prunus* can be classified into three types, which depend on the number of cells wide in the rays. The rays of *Prunus* type 1 have no more than two cells (includes *Prunus avium/padus*). *Prunus* type 2 has three or four cells wide in rays (includes *Prunus spinosa/mahaleb*), and *Prunus* type 3 has more than five cells wide (includes *Prunus spinosa*). ~~as *Prunus* type 2, including *Prunus spinosa/mahaleb*, and *Prunus* type 3 corresponding to *Prunus spinosa/amygdalus*~~. Finally, the family Rosaceae/Maloideae~~ROSACEAE/MALOIDEAE~~ corresponds to several species, including, for example, *Sorbus* and *Crataegus*, that do not always share the same ecological adscription.

4. Results

The anthracological record from Cova Colomera has been ~~A total of~~ 1.117 charcoal fragments, and ~~were recovered at Cova Colomera and~~ 1.,038 ~~of them were~~were identified (Table 2A and 2B). Accumulation curves show an optimal sample size analysed in all layers (Figure 5). The charcoal record shows a wide diversity of taxa, including broadleaves and lianas, such as *Acer* sp (maples), *Arbutus unedo* (strawberry tree), *Buxus sempervirens* (boxwood), *Clematis vitalba* (Traveller's joy), *Corylus avellana* (common hazel), *Fagus sylvatica* (common beech), *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 sp. deciduous (evergreen and deciduous oaks), *Rhamnus alaternus/Phillyrea* (buckthorn),

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Rosaceae/Maloideae (rosales and pomes), Indeterminate angiosperm and cf. *Sambucus* (elderberry), and conifers, such as *Pinus sylvestris* type (scot's pine and black pine), *Taxus baccata* (yew) and *Juniperus* sp. (juniper). The taxa richness remains more or less homogeneous throughout the sequence, although taxa variability was higher in the Late Neolithic layers, especially in Layer CE9.

~~Throughout the sequence, 22 woody species are identified, of the current sub-Mediterranean climatic type. The ubiquity of taxa frequencies remains more or less homogeneous in the sequence, although species variability is higher in the Late Neolithic layers. The recorded species are more variable in Layer CE9, compared to the other layers (Figure 5). The most represented taxa in all archaeological layers are *Quercus* sp. deciduous (oak), *Buxus sempervirens* (box) and *Acer* sp. (maple). Conifer trees and shrubs are also well represented, including *Pinus sylvestris* type (Scots pine), *Juniperus* sp. (junipers) and *Taxus baccata* (English yew). Other woody taxa are less frequent, like deciduous trees belonging to thermo- and meso-Mediterranean taxa, such as *Arbutus unedo* (strawberry tree), *Clematis vitalba*, *Corylus avellana* (common hazel), *Fagus sylvatica* (common beech), *Fraxinus* sp. (ash), *Hedera helix* (ivy), *Lonicera* sp. (honeysuckle), *Pistacia lentiscus* (lentisk), *Populus/Salix* (aspen/willow), *Prunus* sp., evergreen *Quercus* (holm oak), *Rhamnus* (buckthorns) and ROSACEAE/MALOIDEAE.~~

PLACE HERE TABLE 2A. –Middle Holocene anthracological record from Cova Colomera.

PLACE HERE TABLE 2B. Late Holocene anthracological record from Cova Colomera.

~~Anthracological results for Cova Colomera by archaeological layers. Absolute (n) and relative frequencies (%) of charcoal fragments analyzed with species recorded.~~

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Early Neolithic layers CE12, CE13 and CE14 ~~are~~ showed domination of ~~dominated by shrubby *Buxus sempervirens*~~boxwood, with ~~*Quercus* sp. deciduous~~deciduous oak and *Pinus sylvestris* type subsequently. ~~*Acer* sp.~~Maple ~~and *Juniperus* sp. maintain continuously~~shows low values in the three Early Neolithic layers (no more than 8.5%). ~~Nevertheless, the shrubby~~In the other hand, juniper increases in the CE13 layer, although it displays a low presence in the subsequent CE14 layer. Sporadic fragments (≤5%), ~~of other taxa~~ such as *Arbutus unedo*, *Corylus avellana*, ~~*Quercus* sp.~~ evergreen oak, *Pistacia lentiscus*, *Prunus* sp., *Rhamnus alaternus/Phillyrea*, Rosaceae/Maloideae and *Taxus baccata* ~~are~~ were present ~~in different layers~~ (Table 2A). In the same way, ~~*Buxus sempervirens*~~boxwood, ~~Quercus sp. deciduous~~deciduous oak and *Pinus sylvestris* type ~~are~~ were continued to dominedominant ~~dominant~~ in the Late Neolithic layers CE9 and CE10. However, ~~*Acer* sp.~~maple has higher recorded values compared to the previous period, mainly detected in CE10 layer. Also, juniper shows a decreased~~In this layer, *Juniperus* sp. decreases~~. Other taxa, such as *Fraxinus* sp., *Lonicera* sp., *Pistacia lentiscus*, *Populus/Salix*, *Prunus* sp., evergreen oak~~*Quercus* sp. evergreen~~, *Rhamnus alaternus/Phillyrea*, Indeterminate angiosperm 1, *Taxus baccata* and cf. *Sambucus* ~~are~~ were also present~~, although not continuously~~. Likewise, *Taxus baccata* and *Prunus* sp. ~~are~~ were documented in both layers.

PLACE HERE FIGURE 5. ~~Taxonomic saturation~~Taxon accumulation curves ~~for~~ of the Holocene layers ~~from~~ of Cova Colomera.

Early Bronze Age silo EE1 shows high values of ~~*Quercus* sp.~~ deciduous oak. Furthermore, ~~and *Buxus sempervirens*~~boxwood and ~~*Pinus sylvestris* type~~*pine* are well represented (Table 2B). Sporadic fragments of other taxa (≤5%), such as ~~*Acer* sp.~~maple, ~~*Fraxinus* sp.~~*ash*, ~~*Juniperus* sp.~~*juniper*, and ~~*Quercus* sp. evergreen~~evergreen oak ~~are~~

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were also ~~documented~~identified. Finally, Middle Bronze Age layer CE8 ~~is~~ was characterized by a dominant presence of ~~*Quercus* sp. deciduous~~deciduous oak and ~~*Buxus sempervirens*~~boxwood although, compared to the older layers, the values of boxwood ~~have decreased~~was lower. Likewise, scarce appearances of *Acer* sp. *Corylus avellana*, *Fagus sylvatica*, *Fraxinus* sp., *Hedera helix*, *Pinus sylvestris* type, *Prunus* sp., ~~*Quercus* sp. evergreen~~evergreen oak, Rosaceae/Maloideae and *Taxus baccata* have been ~~documented~~identified.

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5. Discussion

5.1. Vegetal landscape transformation and environmental conditions around Cova Colomera

The anthracological results from Cova Colomera have provided key data that allow us to describe the local-scale environment in the Central Pre-Pyrenees, ~~from the~~during the ~~Early Neolithic to the Middle Bronze Age~~Middle-Late Holocene. Anthracological analysis of 1.4~~1~~17 charcoal fragments from Cova Colomera shows the taxa diversity and changes in the representativeness of the relative values along the sequence (Figure 6). Although the anthracological sequence is very homogeneous in terms of the richness and ubiquity of woody taxa, there is a tendency towards a predominance and progressive increase of deciduous forest elements. However, a slight increase of evergreen oaks has been detected in the top of the anthracological sequence.~~Although the anthracological sequence is very homogeneous in terms of diversity, 22 different woody taxa have been identified.~~

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

In accordance with the anthracological results obtained, the local area of Cova Colomera remained relatively stable and dominated by forest communities of deciduous ~~*Quercus*~~*oaks*, with a significant presence of *Buxus 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 *Acer* sp., *Prunus* sp., Maloideae, *Rhamnus cathartica/saxatilis* and *Buxus sempervirens* would indicate temperate and humid climatic conditions. Other shrubby vegetation and small trees, such as *Juniperus* sp. and *Rhamnus/Phillyrea*, could also develop in more open spaces, indicating the existence of clearances. These opened 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 indicates chorotype of micromammals with mid-European requirements, which currently found at higher altitudes from the Pyrenes. Sub-Mediterranean thermophilic elements requiring more humidity, such as *Tilia* and *Pistacia* cf. *terebinthus*, have been identified in the silo EE1 at Cova Colomera, dated in the Early Bronze Age, and *Acer* sp. appears throughout the anthracological sequence. Riverine taxa, such as *Populus/Salix*, and *Fraxinus* sp., have been documented, although their presence is always low. These elements are likely to have been part of the riparian vegetation, occupying the river banks in Montsec mountain range, or in shadier and more humid locations, such as deep narrow gorges. The other represented ~~sub~~circum- and sub-Mediterranean small trees, shrubs and liana, such as *Arbutus unedo*, *Corylus avellana*, *Ilex aquifolium*, *Hedera helix* and *Clematis vitalba* appear in lower frequencies. The occurrence of *Pinus sylvestris* type suggests the presence of conifer forests which suffered a slight decline in the course of the anthracological sequence, mainly during the Middle Bronze Age. These formations would probably be growing at higher altitudes in some nearby areas of the Pre-Pyrenees. ~~-~~*Taxus baccata* would probably develop in shadier areas. ~~Holm oak~~Evergreen oaks and ~~associated~~ sclerophyllous elements, like *Arbutus unedo* and *Rhamnus alaternus/Phillyrea*, showed a low relative frequency throughout the anthracological sequence. However, from a diachronic point of view, a slight increase in evergreen ~~*Quercus* sp.~~*oak* was~~is~~ detected, especially ~~during~~ in the Middle Bronze Age.

~~At present~~

Currently, in Northeastern Spain and Southern France, Mediterranean forests 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). Therefore, Mediterranean forests display ecological characteristics of Mediterranean~~, sub-Mediterranean and~~ and Atlantic climate~~vegetation~~ (Blanco et al., 1997; Carreras and Ferré, 2014). Likewise, the plant community that includes the ~~-holm oak (*Quercus ilex*)~~evergreen oak forest and ~~other~~ an evergreen understory of low trees and high shrubs~~sclerophyllous~~ ~~evergreen taxa~~ (such as *Olea europea*, *Arbutus unedo*, *Rhamnus alaternus/Phillyrea*, *Erica* sp. and *Pistacia lentiscus*) are also identified as ecoregion~~bioclimatic markers~~ of the ~~Mediterranean climate~~ Mediterranean biome, which currently dominates the area. In this aspect, ~~in the area surrounding Cova Colomera, the Mediterranean taxa typical~~ these sclerophyllous taxa ~~of the holm oak forest~~ display low ~~percentages~~ representation ~~of ubiquity values in~~ throughout the anthracological ~~record~~sequence of Cova Colomera. ~~The sclerophyllous~~These taxa may have occupied secondary positions in more drier or sunnier places, probably in deciduous oak forest degradation areas.~~ formations would probably occupy secondary positions in drier or sunnier places, while open and humid~~

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deciduous *Quercus* forests could be dominant in the landscape surrounding Cova Colomera. These open forest formations 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).s

In Central Pre-Pyrenees, from the Early-Middle Holocene boundary (8.2 ka years BP event), the deciduous oak forest would occupy a more extensive territory than at present, favored by a temperate and humid climate (Figure 7). Paleoclimate records from Ppre-Pyrenean ranges, such as Estanya Lake (Morellón et al., 2008), indicate greater water availability in three periods during the Holocene: Early Holocene: 8.5-8.2 ka year BP and Middle Holocene: 6.7-5.9 ka year BP and 4.9-4.2 ka year BP. Although these periods correspond to more humid conditions in the Mediterranean area, brief arid events also occurred at 8.2 and 7.5 ka year BP (Jalut et al., 2009; Bergadà et al., 2018).

PLACE HERE FIGURE 7. Calibrated radiocarbon dates of Cova Colomera in relation of different climate proxies.

However, Sub-Mediterranean thermophilic elements requiring more humidity, such as *Tilia* and *Pistacia* cf. *terebinthus*, have been identified in the silo EE1 at Cova Colomera, dated in the Early Bronze Age, and *Acer* sp. appears throughout the anthracological sequence. Riverine taxa, such as *Populus/Salix*, and *Fraxinus* sp., have been documented, although their presence is always low. These elements are likely to have been part of the riparian vegetation, occupying the river banks in Montsec mountain range, or in shadier and more humid locations, such as deep narrow gorges.

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Taxus baccata records have very low values in pollen sequences, probably owing to the poor pollination rates and morphology difficulties (Chybicki and Oleksa, 2018), although it 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 *Taxus baccata* values between anthracological and pollen data ~~Differences in ubiquity values of *Taxus baccata*~~ may correspond to variable humidity conditions at higher altitudes, which would probably be dominated by coniferous forests. Additionally, the high relative frequency of ~~*Buxus sempervirens*~~*boxwood* in the Cova Colomera anthracological record is noteworthy. Boxwood is a sub-Mediterranean taxon, which currently grows in the montane and subalpine zones and in some southern locations in the Iberian Peninsula, in altitudinal ranges from 26 m. to 2.500 m~~.~~ a.s.l. (Bolòs and Vigo, 1984; 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 deciduous oak forest (Rivas-Martínez, 1984; 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 are 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. ~~The association of the tree taxa~~These taxa ~~is~~ are common in Middle Holocene anthracological sequences ~~in the~~from NE Iberian Peninsula, including littoral sites as well as the inner Pre-littoral ranges, such as in 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 Pont and La Prunera (Piqué, 2005).

According to our results, vegetation transformation dynamics during the Middle-Late Holocene were more or less homogeneous in the Central Pre-Pyrenees. From a local scale, global aridity events would not have affected the vegetation landscape

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structure, and deciduous oak forests, temperate taxa and montane conifers would have developed well in the area. According to our results, it might be suggested that, in the Central Pre-Pyrenees, the 8.2 and 7.5 ka arid events did not cause major changes in the vegetation cover. However, later, during the Late Holocene, xerophilous shrubs and evergreen *Quercus* sp. began to expand in the landscape near Cova Colomera. Rapid global climate change detected in the 4.2 to 3.8 ka event (Mayewsky et al., 2004) and the aridification trend that affected the Mediterranean basin (Fletcher and Sánchez, 2008; Allué et al., 2009; Jalut et al., 2009; Carrión et al., 2010b; Bergadà et al., 2018) could have been more influentialless influential in forest changes towards Mediterranisation of the Central Pre-Pyrenees than former climate events. Likewise, a slight increase of the evergreen oak forest was detected in the Middle Bronze Age layer of Cova Colomera. -*Taxus baccata*, *Acer* sp. and *Buxus sempervirens* 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 dominance of deciduous oak forests, with montane conifers and temperate taxa.

Subsequently, during the Late Holocene, *Taxus baccata*, *Acer* sp. and *Buxus sempervirens* continued to be well represented in Bronze Age anthracological sequences at Cova Colomera, Cova Gran (Allué, unpublished), Cova del Toll (Mas and Allué, 2020) and Institut de Manlleu (Ros, 1995b). The vegetation composition deduced from these anthracological assemblages shows a continuing dominance of mesophilic taxa, with deciduous *Quercus* forests and associated sub-Mediterranean elements, such as *Acer* sp., *Buxus sempervirens* and Rosaceae. Nevertheless, deciduous oak forest and the arboreal vegetation cover retreated slightly, indicating larger clearances. Finally, low

~~percentages of sclerophyllous taxa occurred and *Pinus sylvestris* type has also been documented.~~

5.2. Anthropogenic impacts: human and environment interactions~~involvement~~

The archaeological record at Cova Colomera is associated with short-term occupations, related to herding activities, like foddering, litter-bedding, etc. (Oms et al., 2013; Bergadà and Oms, 2021). The systematic burning of these 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 not an exception. The anthracological sequence shows high taxonomic diversity, including 29 woody taxa. Some of them, could have been part of the herd's fodder diet. However, we cannot exclude the use of some woody taxa as fuel, such as pine, juniper or yew, or as objects and tools that were thrown to the fire after their use. Moreover, ovicaprine herds are a potential agent to reduce undergrowth vegetation. During the winter, browsing is focused on evergreen and semi-deciduous species, while in spring and autumn herbaceous grasses are also browsed (Bartolomé et al., 1998; Osoro et al., 2013). High protein woody species such as *Clematis vitalba*, *Acer opalus*, *Quercus* sp., *Pistacia lentiscus or Arbutus unedo* are currently consumed by ovicaprine herds in Mediterranean areas (Rogosic et al., 2006; Bartolomé, 2014). Other taxa such as junipers and boxwood are rejected by the herds as fodder (Bartolomé, 2014). However, the boxwood's wood is also of good quality: hard, fine and compact, easy to polish and dye, and could have been used for manufacturing objects. The wood produces a 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). In this sense, archaeological work in 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 Bronze Age cultural periods. Two possible scenarios can be discussed. 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) while 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). Alternatively, the second hypothesis postulates the intentional abandonment of caves and rock-shelters due to changes in livestock grazing practices.

Attending to human impact on forest communities in a local scale, from the Early Neolithic to the Middle Bronze Age, the forest cover 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 a non-intensive exploitation of the forests. In this sense, little evidence of intense human activities on the landscape can be found in the Iberian Central Pre-Pyrenees, although the exploitation of the 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

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Conqueta (Mora et al., 2009; Allué, 2011) show slight differences and similarities in the composition of the vegetation landscape. On one hand, the open-air archaeological site of 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, 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 identified livestock practices in the Holocene layers of Cova Gran, especially for livestock enclosure, and interpreted the use of the cave in relation to the transhumance routes through the southern Pyrenees (Polo-Díaz et al., 2014; Burguet-Coca et al., 2020; Martín and Oms, 2021), and also in some mountain 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-Pyrenees valleys with no differences related to 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 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 2.000 m a.s.l., Neolithic populations could consume more or less wood according to the functionality and location of settlements (i.e. Obea et al., 2021). Therefore, the archaeological sites show no evidence of extensive agriculture or substantial modification of the landscapes. In contrast, the transformation of the vegetation landscape appeared to be more intense in Mediterranean coastal areas (e.g., Riera and Esteban-Amat, 1994; Revelles et al., 2015). Nevertheless, there is no uncertainty that anthropogenic activities were important at the local scale particularly in the Late Holocene. T~~t~~he anthropic impact on landscapes during the Early Bronze Age has also been interpreted by the increase in microcharcoal particles associated with the recurrence of fire events in mountain areas (i.e. Carrión et al., 2010b), more intensive land-use dynamics (Rull et al., 2021) and more specialized fuel gathering patterns (i.e. Ros, 1995b, 1998; Piqué, 1999; Allué, 2007; Allué et al., 2009; Vila and Piqué, 2012; Obea et al., 2021).

~~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 Bronze Age cultural periods. Two possible scenarios can be discussed. 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) while 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 et al., 2014; Bergadà et al., 2018). Alternatively, the second hypothesis postulates the intentional abandonment of caves and rock-shelters due to changes in livestock grazing practices.~~

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~~Attending to human impact on forest communities, during the Early Neolithic and Middle Bronze Age, the forest cover does not seem to have changed significantly in terms of either recovery or degradation. This could indicate that human groups carried out a permanent but a non-intensive exploitation of the forests. In this sense, little~~

~~evidence of intense human impact on the landscape can be found in the Iberian Central Pre-Pyrenees, although the exploitation of the 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 slight differences and similarities in the composition of the vegetation landscape. On one hand, the open air archaeological site of Auvelles has yielded an anthracological record of mixed oak taxa in which, although dominated by deciduous oak, evergreen oak is also represented with high ubiquity values (Martín-Seijo and Piqué, 2008). According to the authors, this assemblage could be influenced by specific fuel 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 identified livestock practices in the Holocene layers of Cova Gran, especially for livestock enclosure, and interpreted the use of the cave in relation to the transhumance routes through the southern Pyrenees (Polo et al., 2014; Burguet-Coca et al., 2020; Martín and Oms, 2021), and also in some mountain 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-Pyrenees valleys with any differences related to human pressure causing more open forests in some areas.~~

6. Conclusions

The anthracological analysis of Cova Colomera has documented changes in the vegetation landscape in the Central Pre-Pyrenees, and these are related to specific climatic dynamics and a low anthropogenic impact, especially as regards herding and livestock management activities. The anthracological sequence shows how the local area of Cova Colomera, from the Middle to Late Holocene, remained in the long term dominated by deciduous ~~*Quercus*~~ oak forest ecosystems associated with sub- and supra-Mediterranean deciduous formations, while the coniferous forest gradually receded. According to our results, it seems that in the Central Pre-Pyrenees aridity events did not cause major changes in vegetation cover, since the environmental conditions in the area of study included certain particularities that favored the establishment of a temperate and humid climate. However, during the Late Holocene, ~~xerophytic shrubs and~~ evergreen ~~*Quercus*~~ oaks began to ~~spread on a local scale~~show a slight increase, mainly during the Middle Bronze Age.

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The evidence of the anthropogenic footprint on the landscape during the Middle Holocene is not homogeneous in the NE Iberian Peninsula, as some areas would have displayed certain particularities. Neolithic human groups who settled in the open air and took advantage of the caves and rock-shelters to carry out specialized activities were well aware of the potential of the landscapes. However, the evidence of herding activities during the Neolithic seems to have left ~~an~~ a slight~~incipient~~ pressure on the structure of the different landscapes, especially in inland areas of the NE Iberian Peninsula, like the Central Pre-Pyrenees. Therefore, human presence in this area was probably not intensive. In this sense, we do not observe such intensive exploitation of forest resources, in contrast to 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 be intensive 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 places of settlement. ~~Finally, during the Late Holocene, Bronze Age populations seem to show a more specialized~~

~~selection pattern of forest resources, although with differences in intensity, according to the functionality of the occupations and the place of settlement.~~

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- Fumier deposits of Cova Colomera are the earliest evidence of herding activities among the Central Pre-Pyrenees (Iberian Peninsula), that related by short occupation periods by Neolithic and Bronze Age human groups.
- The new anthracological data from Cova Colomera shows local peculiarities about the structure of the oak woodland ecosystem, and its slight change, related to climatic dynamics, geographic features and activities of herding management.
- In terms of landscape development, human activities do not appear to have affected highly, in contrast to the areas near the Mediterranean seacoast of the NE Iberian Peninsula.

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 1,117 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.

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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Keywords

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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 ka BP to 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-Sampéritz 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 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 and Piqué, 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 (Figure 1).

PLACE HERE FIGURE 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., 2015); 19) Bauma Margineda (Heinz, 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 and Piqué, 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).

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 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 characterized 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 13ºC, with a maximum of 31ºC in July and a minimum of 0ºC in January (Meteocat data 2020 from Camarasa municipality) (Figure 2). The biome of the area is characterized 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.

PLACE HERE FIGURE 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?).

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 characterized 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 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) (Figure 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).

PLACE HERE FIGURE 3. 3D Location map of Cova Colomera, at N42º4’40.892”, E0º40’54.487” (WGS 84).

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).

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

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) (Figure 4).

PLACE HERE FIGURE 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 color, sometimes with platy structure and moderate cementation.

3. Materials and methods

The anthracological analysis of the Middle and Late Holocene archaeological layers at Cova Colomera is based on the study of 1,117 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 x50, x100, x200 and x500. The identification was based on anatomical features described in the atlas of European woods compiled by Schweingruber (1990) and was supported by the reference collection of modern charcoal at the IPHES (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*; *Pinus sylvestris* type includes *Pinus sylvestris/nigra*; and *Quercus* sp. evergreen includes *Quercus 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 *Prunus 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 1,117 charcoal fragments, of which 1,038 were identified (Table 2A and 2B). Accumulation curves show an optimal sample size analysed in all layers (Figure 5). The charcoal record shows a wide diversity of taxa, including broadleaves and lianas such as *Acer* sp. (maples), *Arbutus unedo* (strawberry tree), *Buxus sempervirens* (boxwood), *Clematis vitalba* (traveller's joy), *Corylus avellana* (common hazel), *Fagus sylvatica* (common beech), *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 *Pinus 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.

PLACE HERE TABLE 2A. Middle Holocene anthracological record from Cova Colomera.

PLACE HERE TABLE 2B. Late Holocene anthracological record from Cova Colomera.

The Early Neolithic layers CE12, CE13 and CE14 show a predominance of boxwood, with deciduous oak and *Pinus 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 *Arbutus unedo*, *Corylus avellana*, holm-oak, *Pistacia lentiscus*, *Prunus* sp., *Rhamnus alaternus/Phillyrea*, Rosaceae/ Maloideae and *Taxus baccata* are present (Table 2A). By the same token, boxwood, deciduous oak and *Pinus 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., *Pistacia lentiscus*, *Populus/Salix*, *Prunus* sp., holm-oak, *Rhamnus alaternus/Phillyrea*, indeterminate angiosperm 1, *Taxus baccata* and cf. *Sambucus*, are also present. Likewise, *Taxus baccata* and *Prunus* sp. are documented in both these layers.

PLACE HERE FIGURE 5. Taxon accumulation curves of the Holocene layers of Cova Colomera.

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 characterized 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., *Corylus avellana*, *Fagus sylvatica*, *Fraxinus* sp., *Hedera helix*, *Pinus sylvestris* type, *Prunus* sp., evergreen oak, Rosaceae/Maloideae and *Taxus baccata* are identified.

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 1,117 charcoal fragments from Cova Colomera shows the taxon diversity and changes in the relative values along the sequence (Figure 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.

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

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 *Buxus 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 *Rhamnus 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 *Arbutus unedo*, *Corylus avellana*, *Ilex aquifolium*, *Hedera helix* and *Clematis vitalba*, appear in lower frequencies. The occurrence of *Pinus 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 *Taxus baccata* would have probably developed in shadier areas. In the other hand, holm-oaks and sclerophyllous elements such as *Arbutus unedo* and *Rhamnus alaternus/Phillyrea* show a low relative frequency throughout the 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*, *Arbutus unedo*, *Rhamnus alaternus/Phillyrea*, *Erica* sp. and *Pistacia 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 (Figure 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).

PLACE HERE FIGURE 7. Calibrated radiocarbon dates of Cova Colomera in relation of different climate proxies.

Taxus 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 *Taxus 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 2,500 m a.s.l. (Bolòs and Vigo, 1984; 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 deciduous oak forest (Rivas-Martínez, 1984; 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 (Mayewsky et al., 2004) and the aridification trend that affected the Mediterranean basin (Fletcher and Sánchez, 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 *Clematis 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, 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 2,000 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 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 specialized 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 specialized 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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Figure2

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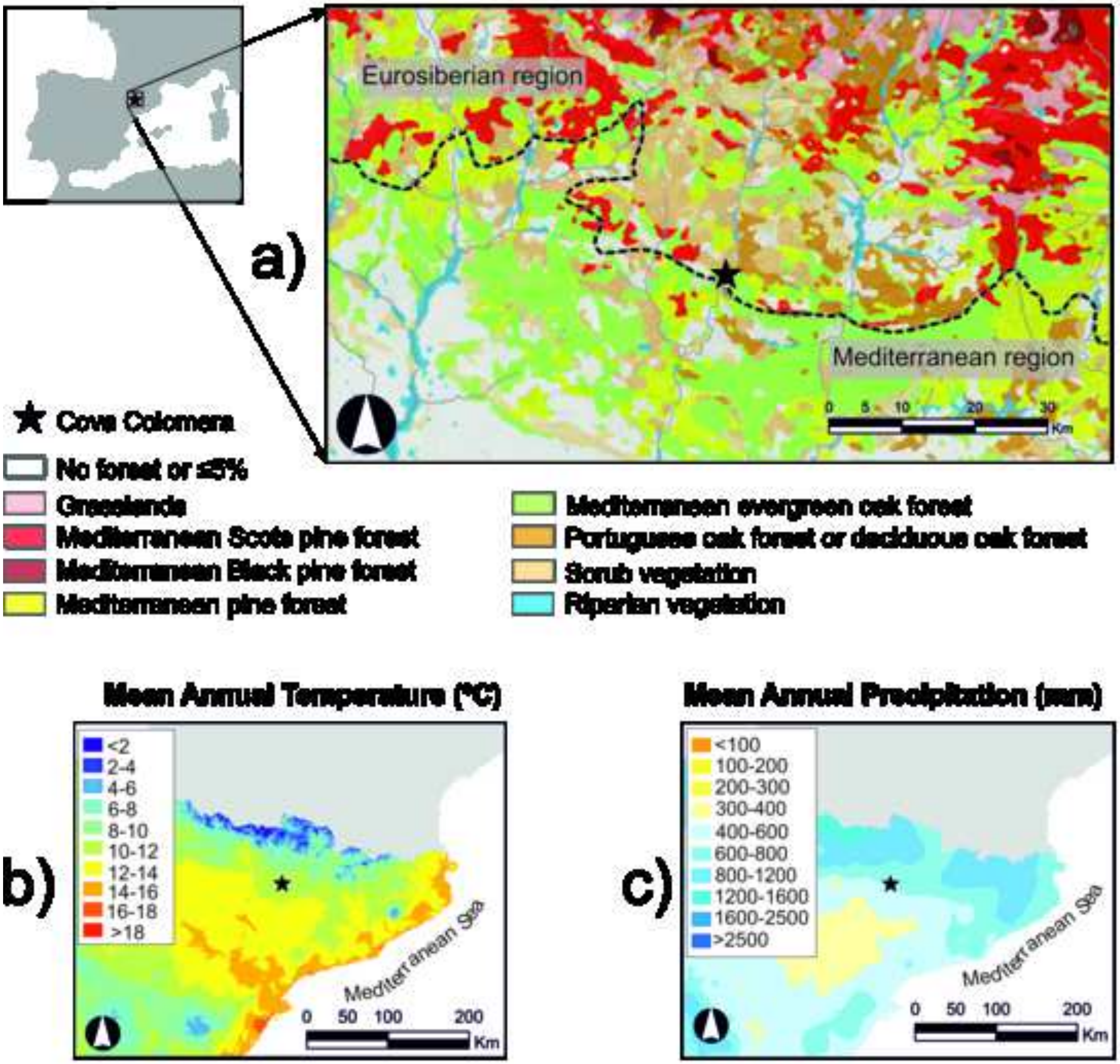

Figure3

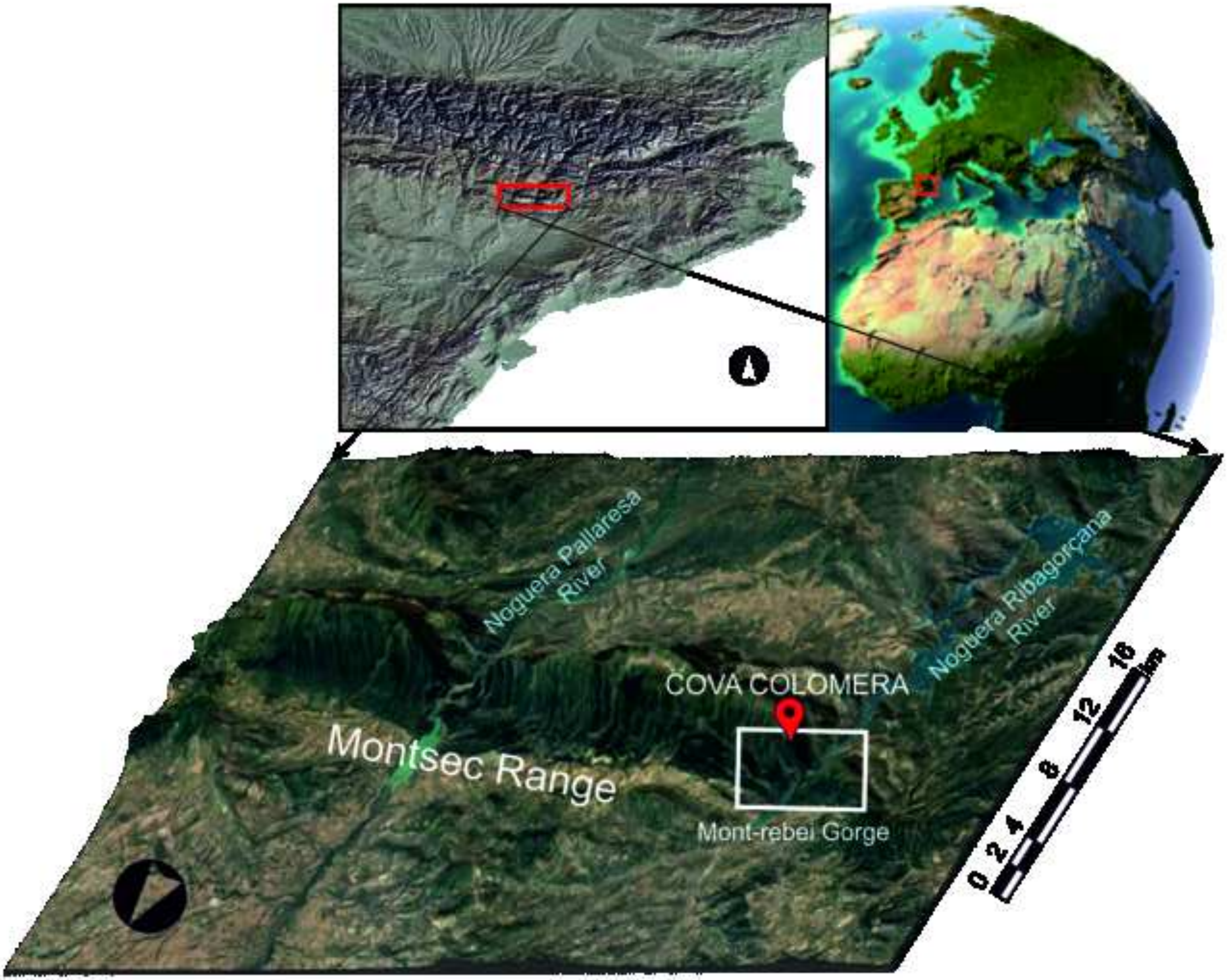
Noguera Pallaresa River
Noguera Ribagorçana River
COVA COLOMERA
Montsec Range
Mont-rebei Gorge
0 2 4 8 12 16 km

Figure4

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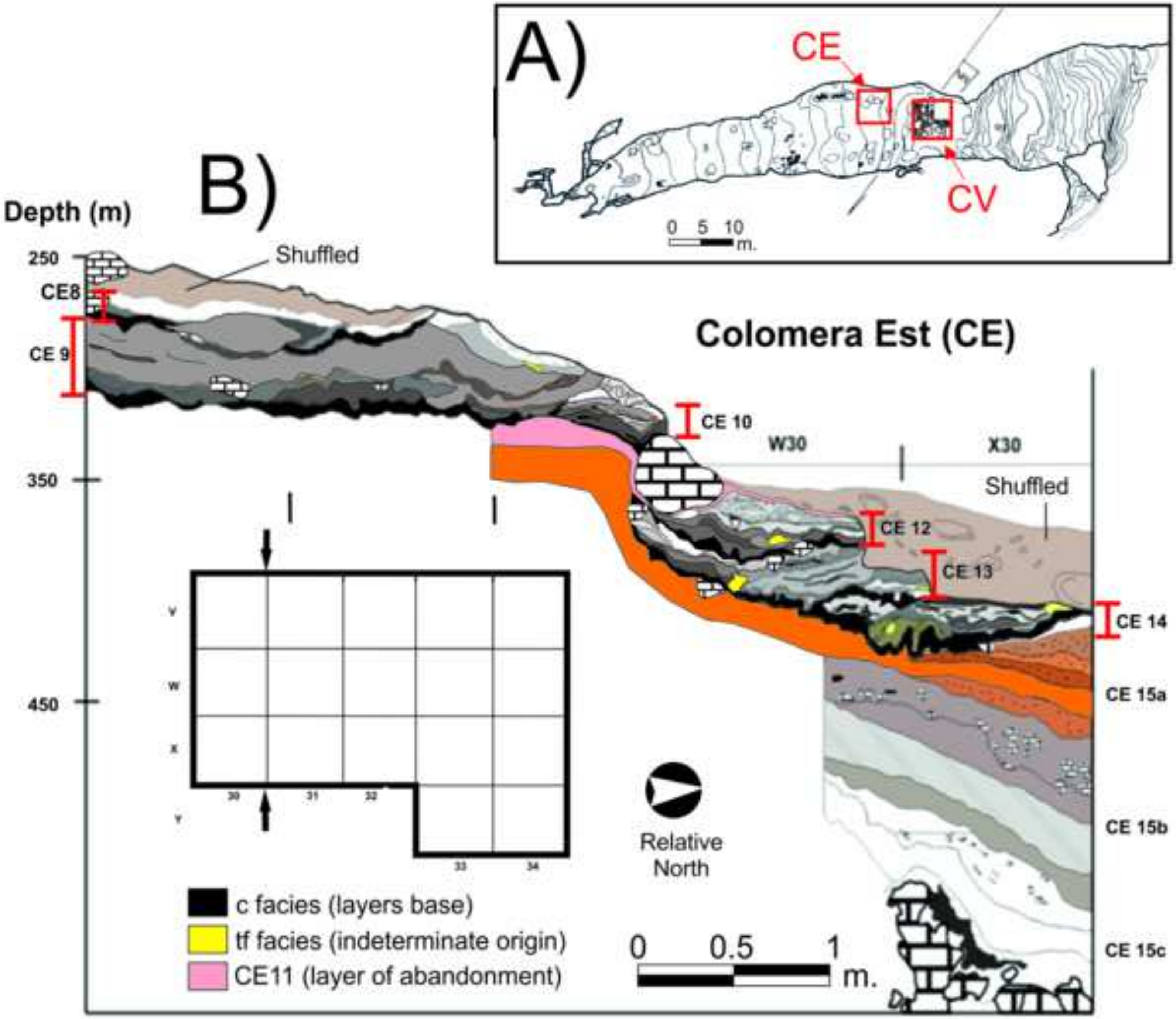

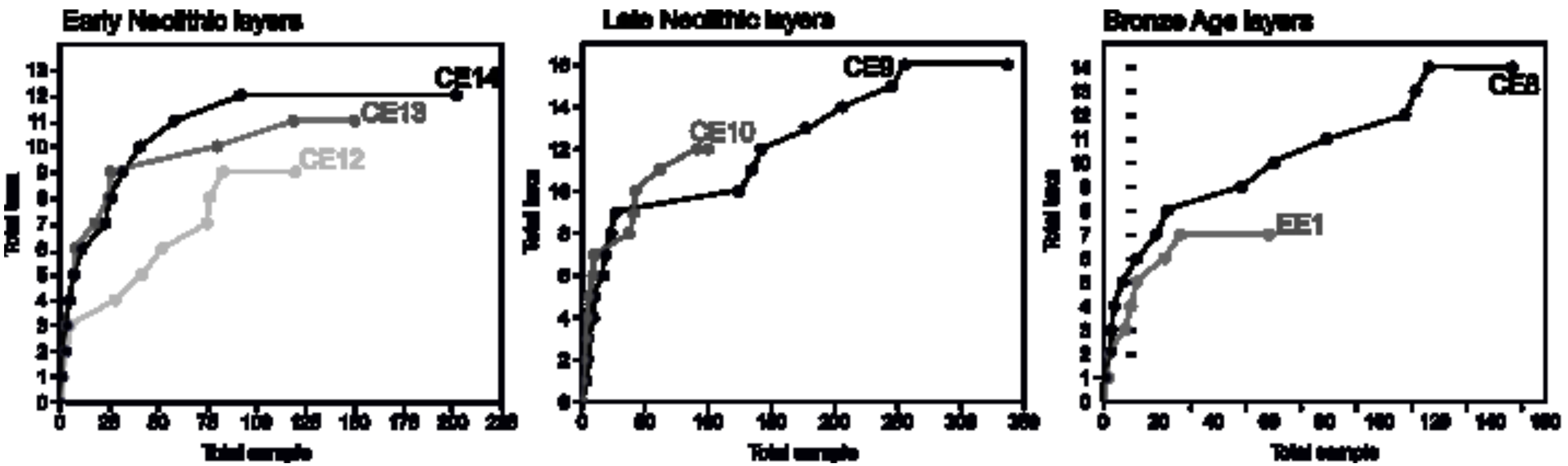
Early Neolithic layers
CE14
CE13
CE12
Total sample
Late Neolithic layers
CE9
CE10
Total sample
Bronze Age layers
CE8
EE1
Total sample

Figure7

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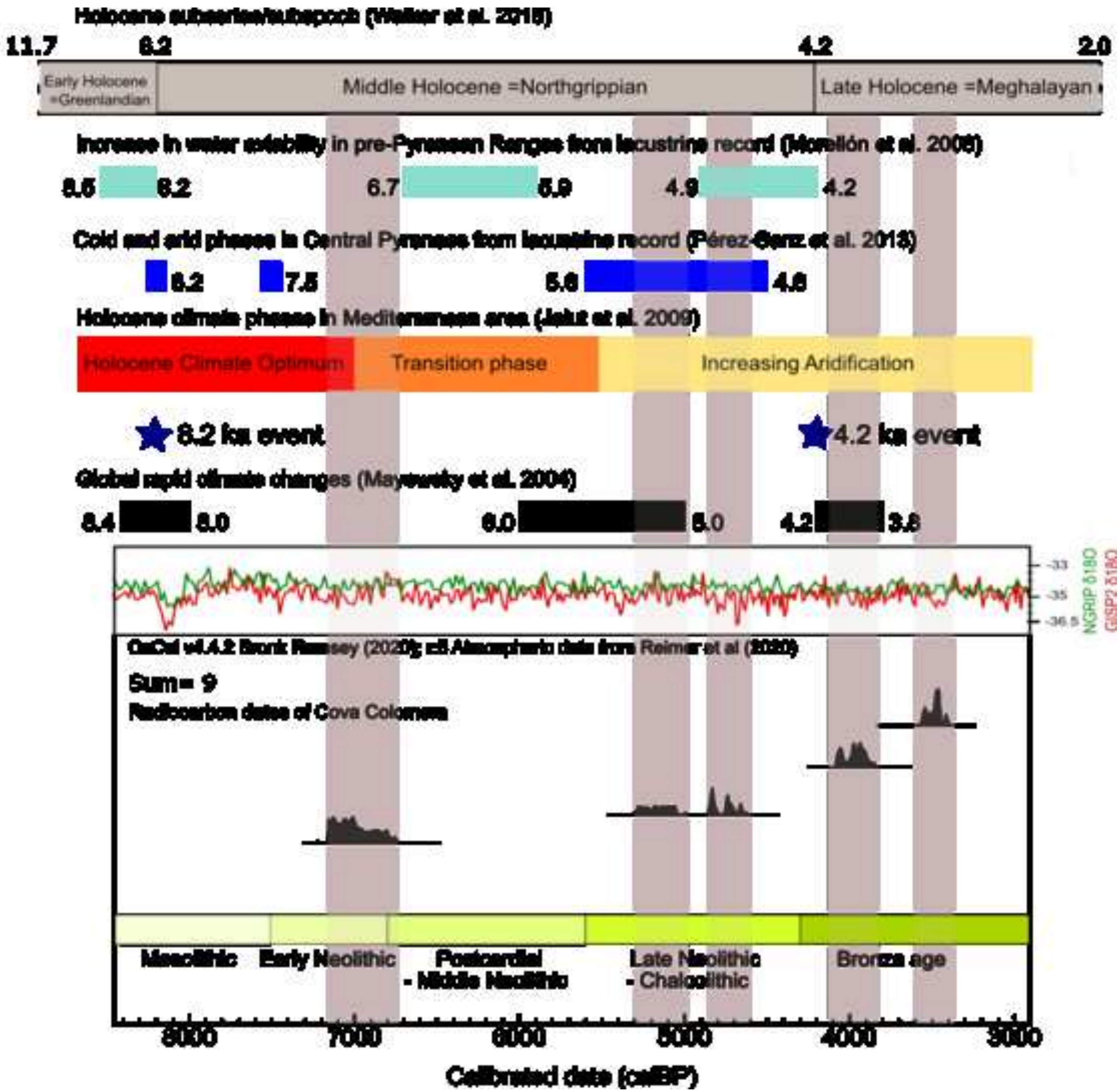

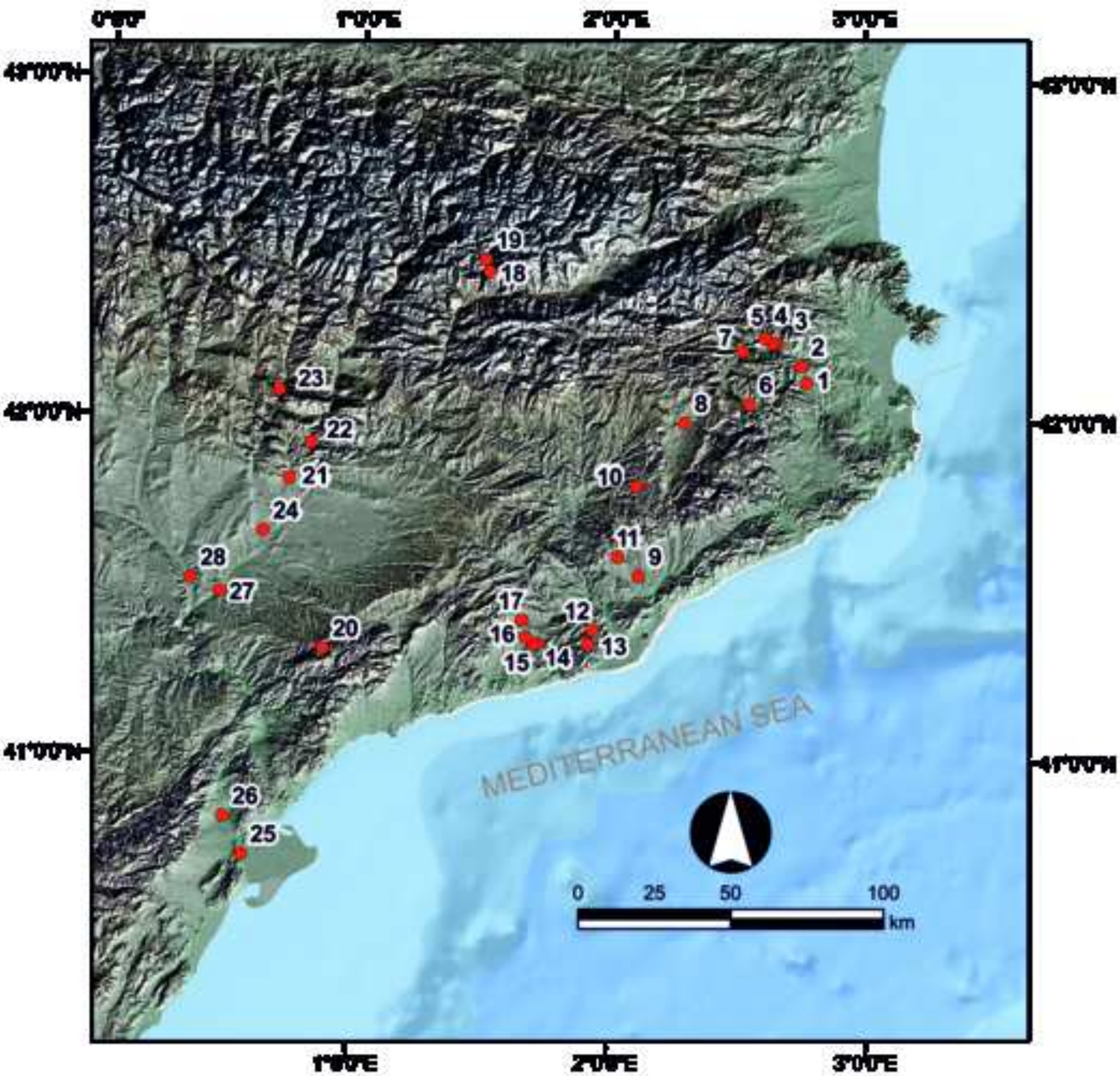
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Figure 6

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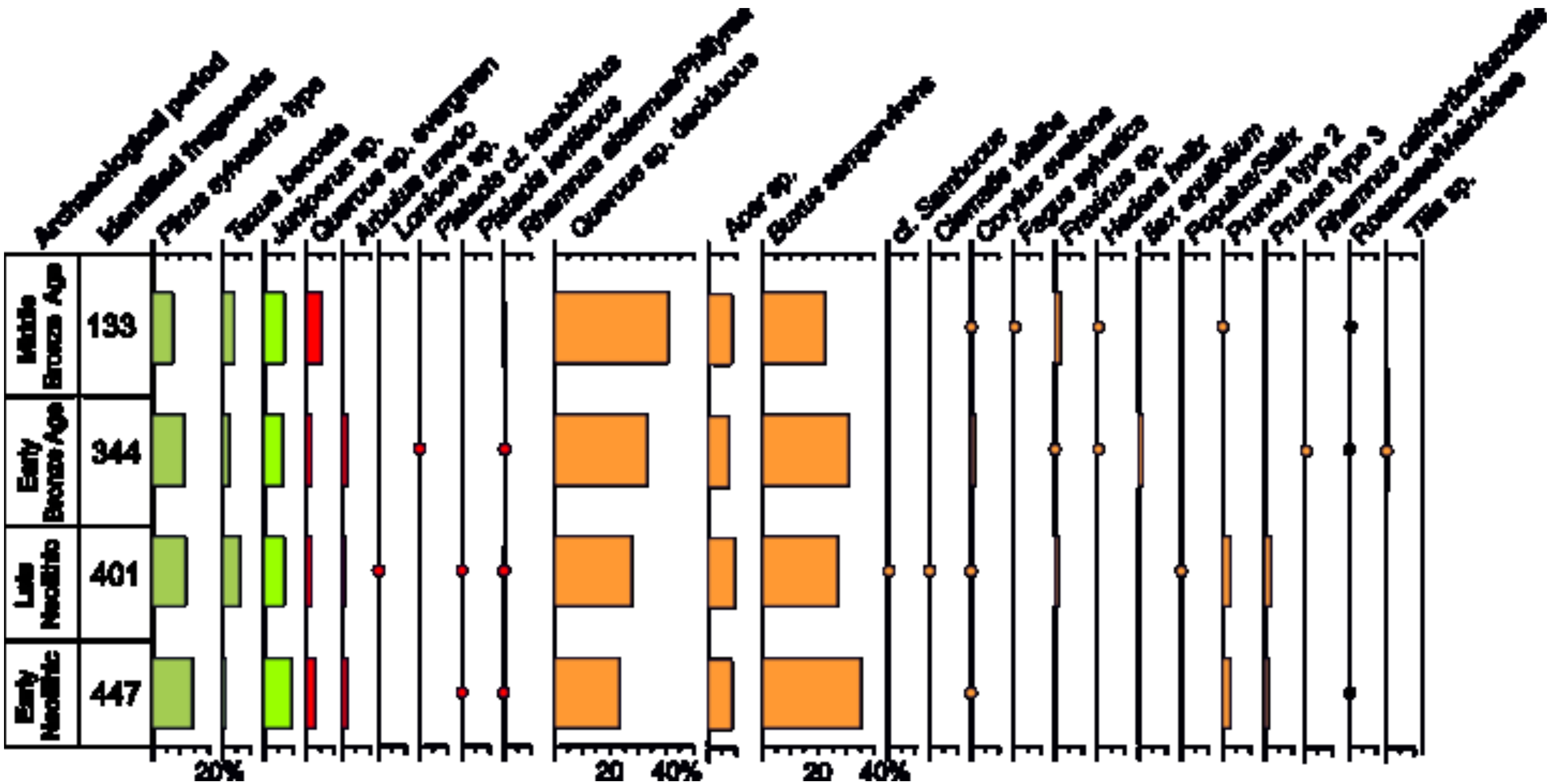

Table 1. Compilation of published radiocarbon and calibrated dates from the Holocene sequence of the Cova Colomera test pit CE.

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-23633	3260±26	1630-1470	3561-3400	Oms et al., 2015
CE8	*Fumier*	Middle Bronze age	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	Beta-140550	3280±40	1660-1440	3579-3395	Oms et al., 2015
EE1	Silo	Early Bronze age	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	OxA-17732	3659±30	2170-1930	4086-3896	Oms et al., 2009b
EE1	Silo	Early Bronze age	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	Beta-241704	3630±40	2130-1890	4084-3839	Oms et al., 2009b
CE9	*Fumier*	Late Neolithic	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	Beta-265439	4230±40	2960-2680	4863-4621	Oms et al., 2015
CE10	*Fumier*	Late Neolithic	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	OxA-17331	4500±32	3400-3040	5305-5041	Oms et al., 2015
CE12	*Fumier*	Early Neolithic	*Buxus sempervirens*	Manual flotation	AMS ^{14}C	Beta-248523	6020±50	5060-4780	7146-6737	Oms et al., 2013
CE13	*Fumier*	Early Neolithic	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	Beta-240551	6150±40	5250-4960	7164-6909	Oms et al., 2013
CE14	*Fumier*	Early Neolithic	*Triticum aestivum/durum*	Manual flotation	AMS ^{14}C	OxA-23634	6170±30	5250-5010	7163-6964	Oms et al., 2013

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

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

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: