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Wood uses at El Mirador Cave (Atapuerca, Burgos) based on anthracology and dendrology

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Abstract

El Mirador cave contains a continuous sedimentary deposit of burnt sediments identified as fumier layers, corresponding to burnt sheep and goat dung. This sediment infilling has yielded a large number of charcoal remains. The general objective of this study is to contribute to the knowledge of western Mediterranean Holocene vegetation and land use history by combining classical wood charcoal analysis with dendrological charcoal studies. A specific aim of this work is to characterize the origin of the anthracological assemblage. Anthracological analyses show a continuous sequence dominated by oaks, in which deciduous oaks exhibit higher values during the early Neolithic, with an increase in evergreen oaks from the middle Neolithic onwards. The anthracological data suggests that human activities and climatic variations throughout the Holocene caused changes in the forests. The dendrology results on a small Quercus sp. deciduous sample suggests that the wood used corresponds to young branches bearing tree rings with a rapid growth rate, which might indicate that the trees were regularly shredded. Both approaches suggest that oak was probably used as leafy fodder, and its remains were burnt during repeated combustion processes.

Keywords

Tree rings ; Charcoal ; Mid-Holocene ; Leafy fodder ; Fuel ; Iberian Peninsula

1. Introduction

Anthracological assemblages from European cave deposits have provided important data for the understanding of different aspects related to the behaviour of human groups during the Neolithic and Bronze Age (Thiébault, 1988, 2001, 2006; Argant et al., 1991; Brochier et al., 1998; Delhon et al., 2008). In the Mediterranean area, these assemblages are often sediment deposits made up of sheep and goat dung, called *fumier* deposits (Argant et al., 1991; Brochier et al., 1998; Badal, 1999; Bergadà et al., 2005; Angelucci et al., 2009). The systematic burning of these layers often provides rich anthracological records. The charcoal remains from these types of sequences can be associated with different activities such as the use of fuel (for domestic hearths or dung pile burning), the use of wood left over from other previous purposes (posts, objects, tools), and the use of leafy fodder.

Leafy hay is an important source of food for herds in agro-pastoral communities. It is usually grazed, and some species are especially sought after for goats and sheep. The presence of wood charcoal in agro-pastoral archaeological contexts has been often described as resulting from woody fodder brought into caves to feed animals. Several archaeological and archaeobotanical studies have suggested that the practice of using leafy fodder to feed livestock began in the Neolithic (Rasmussen, 1990a, 1990b, 1993; Argant et al., 1991; Akeret and Jacomet, 1997; Charles et al., 1998; Badal, 1999; Thiébault, 2001, 2005; Peña-Chocarro et al., 2005; Badal and Atienza, 2008; Hejcman et al., 2014). Moreover, ethnographic sources have illustrated that livestock like leafy fodder and that it is an important source of animal feed in the absence of pastures, mostly during winter (Bolaños, 1960; Solecki, 1979; Halstead et al., 1996; Halstead, 1998; Zapata and Peña-Chocarro, 2003). Sheep and goats have different eating habits and different ways of eating, but they both appreciate the leaves and tender shoots of woody species. Wood has been also used as fuel, either as a by-product of leafy fodder or as a result of the direct gathering of firewood. Firewood has been used in domestic hearths as day-to-day fuel and as kindling for dung combustion (Peña-Chocarro et al., 2005; Allué et al., 2009). The gathering of wood for different purposes can lead to forest management activities, which may have been implemented since the early Neolithic. However, several key issues such as the archaeological context, changes in tree ring growth rhythm and width, physical alterations and relationship between branch age and diameter, must be explored in order to identify direct evidence that would support this interpretation (Out et al., 2013).

Anthracological analyses provide a list of taxa from which selection patterns can be deduced according to taxa assemblages and variations in values. For leafy fodder, evidence of higher values of certain species or fluctuations in values over a sequence of species in the assemblages, such as *Fraxinus*, *Olea* and *Quercus*, have been suggested as indicating a preference for these species as fodder (Badal, 1999; Thiébault, 2001, 2006; Peña-Chocarro et al., 2005; Allué and Euba, 2008; Allué et al., 2009).

Other disciplines, such as dendrology, make it possible to characterize these assemblages beyond the taxonomic identification provided by traditional anthracological analyses. Dendrology has traditionally been used to obtain chronological series through the measurement of tree ring widths of the same species. The aim of these studies has typically been to reconstruct ecological and climatic conditions (Carrión, 2006). However, the observation of changes in anatomical structure through anthracological and dendrological studies has also been used to identify direct evidence of such conditions (Thiébault, 2006; Marguerie and Hunot, 2007; García-Martínez and Dufraisse, 2012; Out et al., 2013). These studies focus on the characterization of wood remains through trigonometric methods in order to identify the minimum calibre of the used wood (Dufraisse, 2006; Marguerie and Hunot, 2007; Dufraisse and García-Martínez, 2011; García-Martínez and Dufraisse, 2012; Paradis-Grenouillet et al., 2013). Other studies are specific to the study of pruning and leafy fodder uses based on archaeobotanical evidence and dendrological analyses (Rasmussen, 1990a, 1990b, 1993; Haas and Schweingruber, 1993; Bernard, 1998; Rozas, 2005; Bernard et al., 2006; Thiébault, 2006).

The best materials for use in dendrological studies are mature individuals with straight rings with a length of at least 2 mm and an age of between 60 and 120 years, with as many tree rings as possible and regular growth (Feuillat et al., 1997; Haneca et al., 2009). Therefore, charcoal fragments from archaeological sites are not the most suitable material for dendrology. This is mainly due to combustion alterations (cracks, vitrification or mass reduction) and postdepositional processes (fragmentation, cracks, or alteration by microorganisms) affecting the remains. However, there are very few sites with the required humid or dry anaerobic conditions that contain wood remains with the necessary characteristics (Billamboz, 1987, 1992). As a consequence, it is more common to recover charcoal fragments from archaeological sites, and several studies have been conducted within the framework of anthracology in the past few decades (Ludemann and Nelle, 2002; Dufraisse, 2006; Marguerie and Hunot, 2007; Out et al., 2013). These records rarely provide a long series of tree rings. Nevertheless, these types of studies are providing new data on environmental changes and forest management.

The aim of this work is to identify evidence characterizing the origin of the anthracological assemblage. This will allow us to understand aspects regarding the use of wood at the site. The study is based on the anthracological and dendrological analyses of the charcoal remains from the Neolithic and Bronze Age layers at El Mirador.

2. Site description

El Mirador cave (Ibeas de Juarros, Burgos) is located in the Sierra de Atapuerca at 42º20′58″ N and 03º30′33″ W, at 1033 m.a.s.l. (Fig. 1). El Mirador is a continuous deposit formed by a successive deposition of anthropic origin containing various different combustion phases (Vergès et al., 2002, 2008; 2016; Angelucci et al., 2009). The chrono-cultural sequences studied in this work encompass the Neolithic to the Bronze Age layers with a chronology of between 7030 ± 40 yrs for layer MIR24 BP and 3038 ± 40 yrs BP for layer MIR4 (Fig. 1) (Vergès et al. 2016).

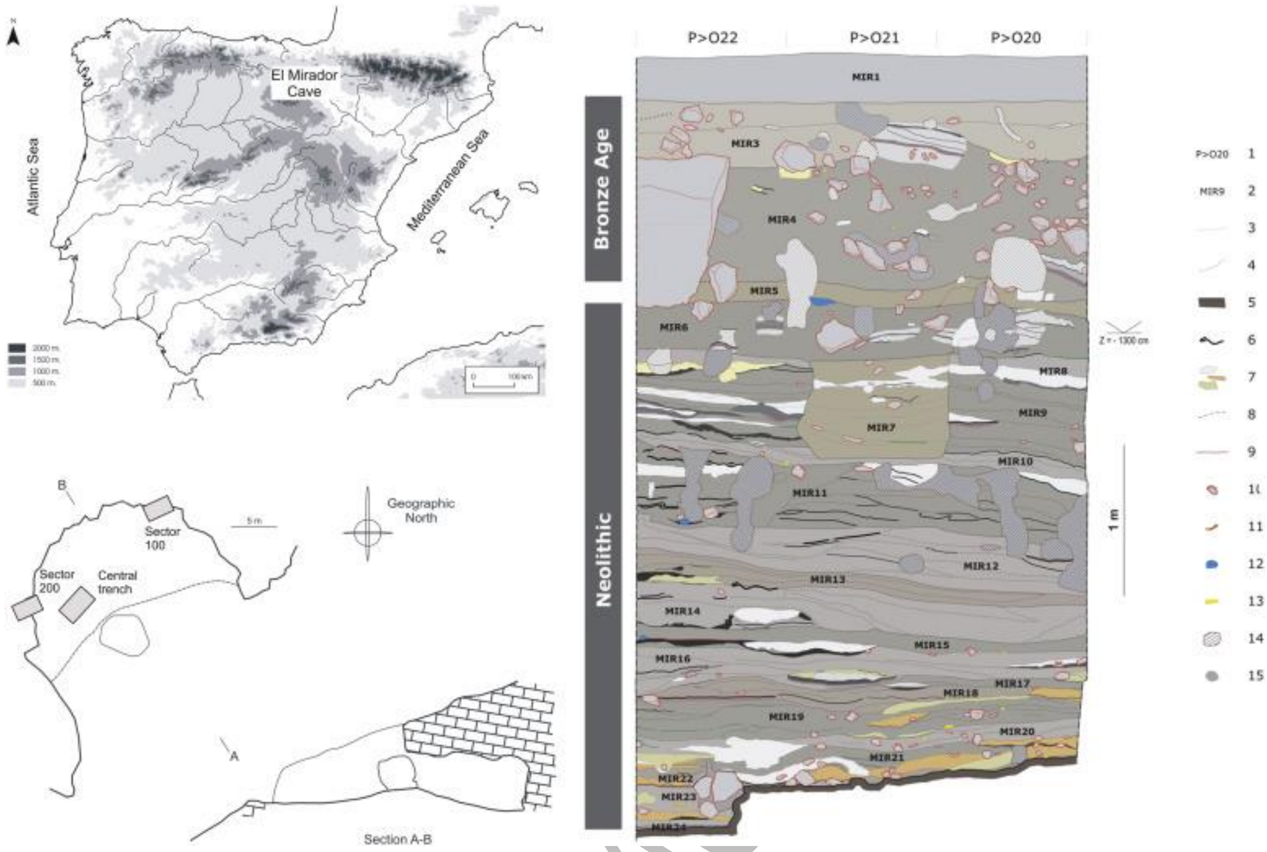

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Fig. 1. Location of El Mirador cave and stratigraphic sequence.

The archaeological record recovered in the 6 m2 test trench is mainly made up of archaeobotanical remains, including charcoal and seeds (Allué and Euba, 2008; Rodríguez and Buxó, 2008). Microremains from sediment samples include pollen and phytoliths (Cabanes et al., 2009; Expósito, 2016). There are also faunal remains dominated by sheep and goat bone remains as well as a few ceramic and lithic remains. In general, the artefact assemblage, the bioarchaeological remains, and the geoarchaeological characterization of the deposit suggest that the excavated sequence was used as a livestock pen (Martín et al., 2009; Vergès et al., 2002, 2008; 2016; Angelucci et al., 2009).

3. Materials and methods

The anthracological study is based on the taxonomic identification of 5467 remains from 17 layers. The studied remains correspond to the 4 mm fraction of the flotation sediment. The charcoal remains were identified using an optical microscope (Olympus BX41) with reflected light at ×5, ×10, ×20, and ×50. A reference collection and the Schweingruber (1990) wood anatomy atlas were used to support our identifications. Each charcoal sample was fragmented by hand to obtain the three anatomical sections that characterize the wood cell structure of each taxon. The taxonomic categories comprise either species, species groups, genera or families according to distinctness of wood anatomical character combinations.

A dendrological analysis was applied to a selection of *Quercus* sp. deciduous remains. Not only was this one of the most abundant and recurrent taxa in the sequence, but its anatomical characteristics also make it possible to effectively analyse its rings. In fact, the most suitable species for dendrology are those in which early wood is easily distinguishable from late wood. *Quercus* sp. deciduous exhibits a gradual transition from early to late wood and between growth rings. However, the ring porous character means that early wood can be clearly distinguished from late wood. Moreover, *Quercus* sp. deciduous tree rings are clearly visible at low magnifications using a binocular lens. This makes the dendrological analysis much more feasible, as a binocular lens provides greater depth of field.

The objectives of dendrological measurements are to identify minimum diameter, to define tree ring curvature, to determine growth rate and to measure wood growth. To these ends, we used a binocular lens (Zeiss Stemi 2000-C) with magnifications from ×0.65 to ×5, plus ×10 with an ocular lens. Images were captured using an Inside FireWire Spot 2 Image Sample camera and measurements were taken using Spot Advanced software.

For the dendrological analysis, we first selected 430 *Quercus* sp. deciduous charcoal remains. This large assemblage of remains had many limiting factors that hindered the use of different measurements, as every fragment must have more than two rings and exhibit a multiseriate ray or contain bark. The presence of multiseriate ray is required to define the radius and is better observed with a binocular lens than uniseriate rays. Some of the selected samples showed unclear growth direction, and there were also a lot of small twigs with irregular growth and unclear tree rings. Thus, from the initial sample, analyses could only be performed on 209 fragments. Not all measurements could be taken on each of the samples and the number of analysed fragments per layer varies from 3 to 51.

The minimal diameter was measured according to previous works based on trigonometry (Rozas, 2005; Dufraisse and García-Martínez, 2011; Paradis-Grenouillet et al., 2013). In this work, we used the Pythagorean Theorem for the isosceles triangle, drawing a hypothetical triangle on the charcoal fragments in which the sine of the angle is equal to the length of the opposite side (d/2) divided by the hypotenuse (R). Therefore, the hypotenuse (R) is equal to the opposite side length (d/2) divided by the sine of angle ('a') formed by the hypotenuse of the adjacent side (Fig. 2). This analysis was done on 98 charcoal fragments. It was also applied to seven modern samples from different deciduous oak species (*Quercus faginea* and *Quercus pyrenaica*) from the Sierra de Atapuerca. In these samples, four measurements were taken for each of the samples.

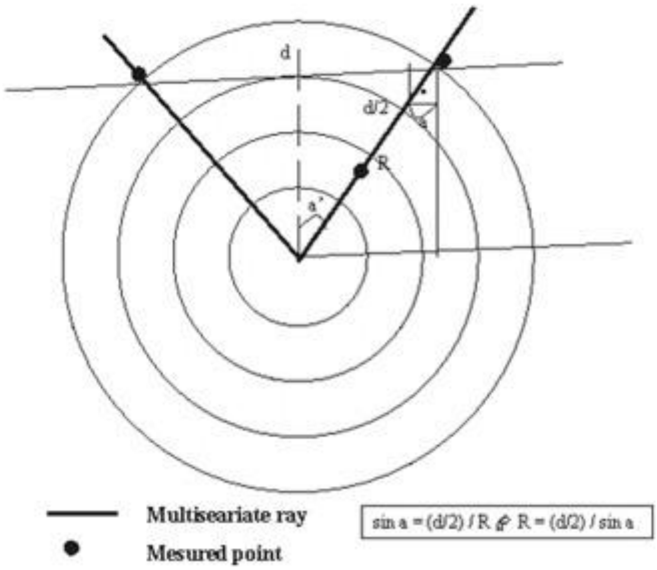

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Fig. 2. Schema showing the measurements used to find minimal diameter.

Using a binocular lens and image capture software, we measured the charcoal fragments to obtain values for 'd' and 'a' (Fig. 2). Firstly, we obtained the value of the line that connects the two multiseriated rays with the one farthest from the centre growth ring ('d'). This measurement had to exceed 2 mm. The result of dividing the obtained 'd' value by two equals the length of the opposite side of our isosceles triangle. Secondly, we obtained a perpendicular line from d, and finally, we drew a line on the multiseriated ray and calculated the angle formed between the perpendicular line of 'd' and the multiseriated ray. This angle, 'a', should be larger than 2°. After this, we applied the formula to obtain the length of the hypotenuse, which is to say from the ray (R) that was multiplied by 2 to obtain the diameter: D (R*2) = [(d/2)/sin a'] * 2.

Tree ring curvature based on Marguerie and Hunot (2007) is divided into four categories: strongly curved, moderately curved, weakly curved and straight. These characteristics were documented in 195 fragments.

The annual growth rate was measured by counting the tree rings and measuring the length of each of them. From these measurements we obtained the mean tree ring width, grouped into 0.5 mm classes, and the growth rate of each fragment based on the number of tree rings per cm. This analysis was conducted on 194 fragments for tree ring widths and 175 charcoal fragments for growth rate.

4. Results

4.1. Anthracological results

The anthracological material from El Mirador has yielded 18 taxa. Taxonomic diversity in most of the layers varies from five to eight taxa, with the exception of layer MIR4, with up to 15 taxa. The results of the anthracological analyses show that oaks (evergreen and deciduous oaks) were the most frequently used species throughout the sequences, with rates of >60% in all layers (Fig. 3). Other taxa were also present in lesser percentages <20%. At the bottom of the sequence, deciduous oaks are more significant, as are other taxa such as *Pinus sylvestris* type, *Fraxinus*, and *Corylus avellana*, among others, suggesting a wetter environment. At the top of the sequence, evergreen oaks exhibit higher values, with lower values of *Fraxinus* and *Corylus*, indicating an increase in aridity. Finally, *Fagus* and Fabaceae are only present in the Bronze Age layers (Fig. 3).

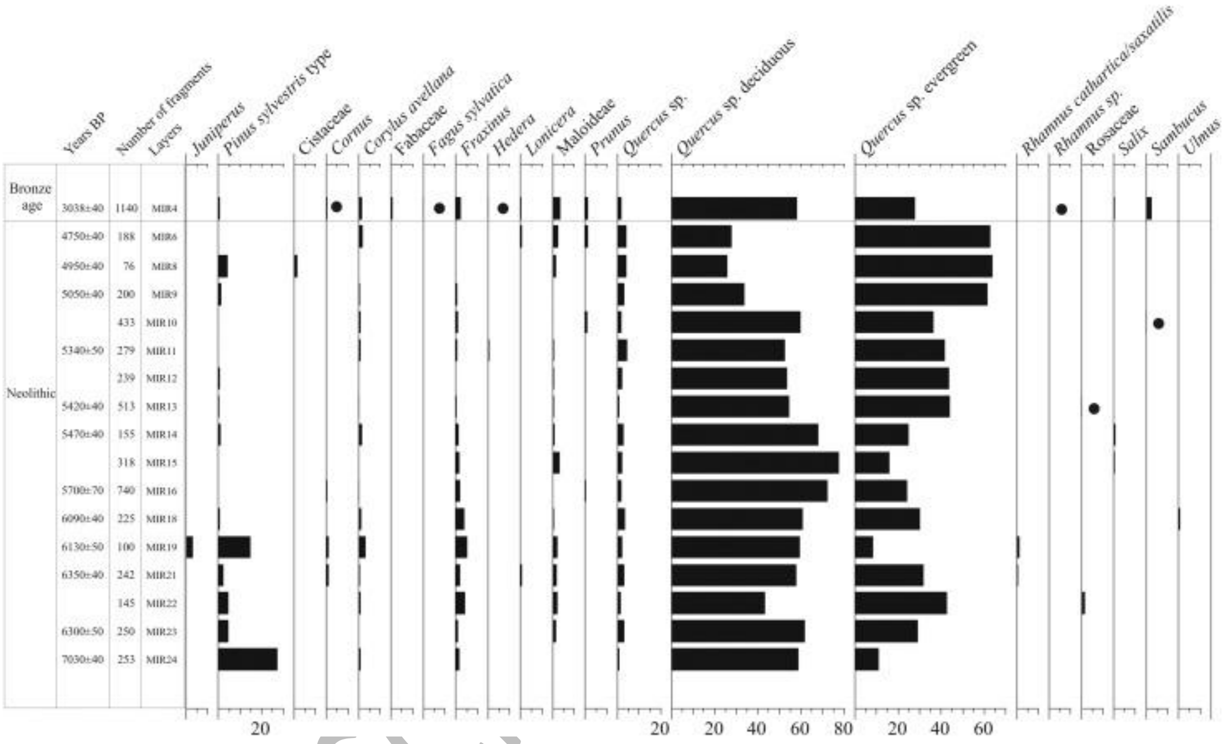

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Fig. 3. Anthracological diagram of El Mirador.

4.2. Dendrological results

The results of the measurements for minimal diameter were less than 3 cm for most of the remains (Fig. 4). Two of the samples had extreme values and were excluded from the figure. One of these fragments from MIR10 was found to have a minimal diameter of 12.63 cm and the other one, from MIR13, a diameter of 46.53 cm.

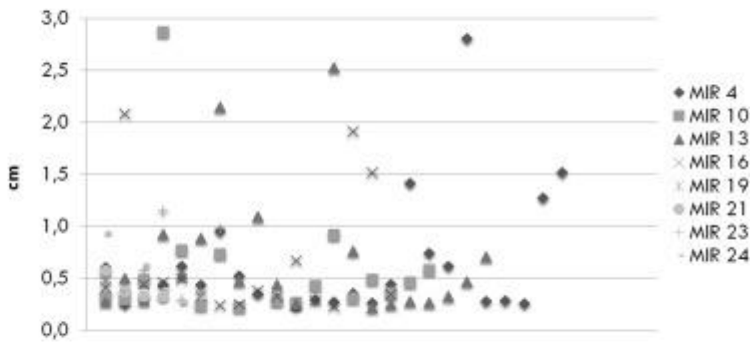

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Fig. 4. Results of the minimal diameter analyses of the charcoal remains from El Mirador.

Fig. 5 shows that the tree ring curvature in layers MIR4, MIR13 and MIR21 is strongly curved and moderately curved, whereas in MIR10 the values are similar for all categories. Meanwhile, in layers MIR16, MIR23 and MIR24 the weakly curved and straight values are higher.

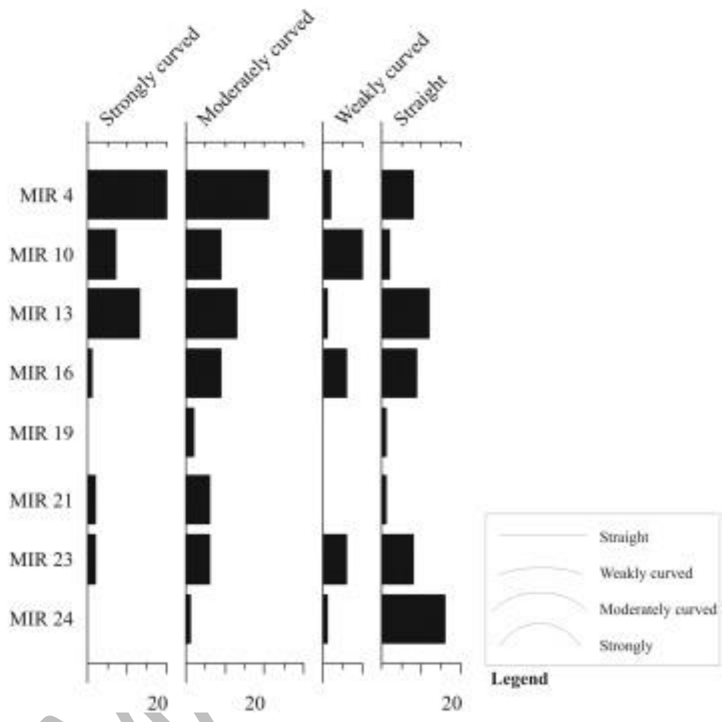

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Fig. 5. Tree ring curvature diagram from El Mirador.

Fig. 6 shows the results of the average tree ring width per level analysed. The average width is divided into 0.5 mm classes to better view the results. Most fragments tested had an average tree ring width of between 0.1 and 1 mm (Fig. 6). The longest average width was 2.5 mm. Fragments with 1. to 1.5 mm represented less than 12% of the sample. The results of the average tree ring width show that the fragments from El Mirador are young, as very few fragments have tree rings exceeding 2 mm in width.

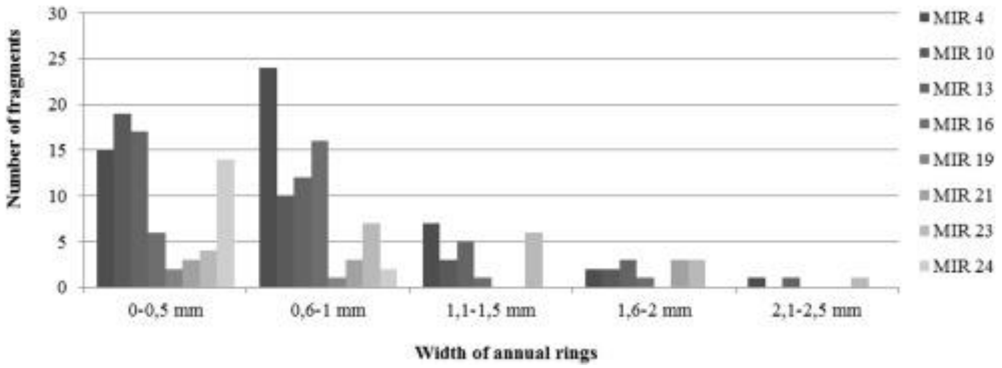

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Fig. 6. Average tree ring width per level at El Mirador.

The relative values of the ranges of ring number per cm were very similar at all analysed levels. This information provides insight into heartwood growth. Fig. 7 shows that most of the fragments have between 6 and 10 growth rings per cm. Fragments with fewer growth rings per cm account for 15.42% of the sample. The smallest values, with the largest number of rings between 21 and 35 rings, representing less than 8% for each category (Fig. 7).

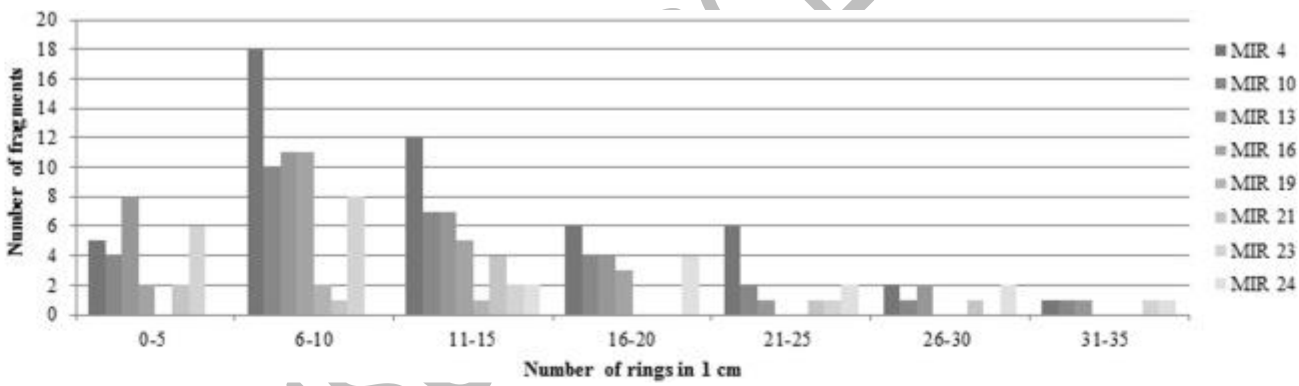

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Fig. 7. Number of rings per 1 cm from El Mirador.

5. Discussion

The study of the sequence infilling suggests that the charcoal remains at El Mirador are the result of wood combustion for different purposes, including wood used for fuel, waste from other activities, and fodder waste mixed in when feeding the fire (Allué and Euba, 2008; Vergès et al., 2008; Angelucci et al., 2009). According to archaeological and geoarchaeological data, the cave was used as a pen for sheep and goats (Vergès et al., 2002; Angelucci et al., 2009). Therefore, we can suggest that the main use of wood at El Mirador was probably for leafy fodder and fuel. This wood use, which occurred throughout the Neolithic and into the Bronze Age, may be the result of the systematic exploitation of the surrounding woodland, possibly suggesting forest management.

Forest management can be identified through different activities carried out on the woodland. Forest clearing and different types of pruning (shredding, pollarding, pruning or coppicing) allow the forest to regenerate, prevent fires, and enhance the productivity or exploitation of resources or species (Fig. 8). Thus, the goal of forest management by human groups is to gain control and productivity of plant biomass for the purpose of obtaining more resources. The identification of past forest management strategies is based on traditional archaeobotanical studies that consider variations in taxonomic records and the presence of certain species, and from there infer associated human activities (Delhon et al., 2008; Allué et al., 2009; Rius et al., 2009; Out et al., 2013). These studies only provide indirect evidence based on archaeobotanical records. Archaeological evidence, such as the recovery of tools used for cutting wood, is scarce, in addition to being indirect (Bosch et al., 2006). On the other hand, direct evidence suggesting the intentional modification of the woodland is difficult to ascertain due to the limited data yielded by anthracological and wood remains (Out et al., 2013).

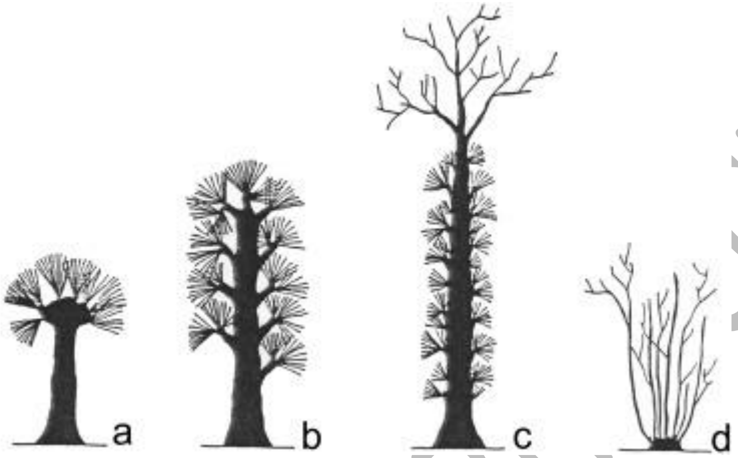

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Fig. 8. Schematic drawing of the different types of pruning modified from (Rasmussen, 1990a) a) pollarded, b) pollarded with intact trunk, c) shredded, d) coppiced.

The anthracological and dendrological data obtained from the study of the charcoal remains from El Mirador cave provide points for discussion on various aspects related to the use of wood. Charcoal fragments are included in the sediment cave infilling, which is mainly comprised of dung layers resulting from the burning of animal droppings for cleaning purposes and to reduce the dung volume (Angelucci et al., 2009). The wood may be a by-product of other activities, such as the use of leafy fodder for livestock or wood for fuel. The charcoal could also have been previously used as a building material for posts, tool making or other purposes. Interpretation in any direction is difficult because all of these processes are likely to have occurred in the cave and are consistent with the different activities carried out by the occupying groups. However, the results of our anthracological and dendrological analyses point to components of livestock and forest management.

The anthracological sequence of El Mirador shows the importance of the different species of the genus *Quercus* growing in the vicinity of the cave. During the early stages of the Neolithic occupation of the cave, there was a clear dominance of *Quercus* sp. deciduous in relation to evergreen oaks (Fig. 3). The opposite trend is observed in MIR9. Moreover, other elements characterize the sequence: first, the importance of *Fraxinus*, *C. avellana* and Maloideae at the base of the sequence, with an abundance of *Quercus* sp. deciduous. These taxa characterize a more humid environment and the greater extension of mesophilous taxa during the early Neolithic. In MIR9, an increase in evergreen oaks and a decrease in *Fraxinus*, *C. avellana* and Maloideae suggest drier environmental conditions, which is in agreement with the general climatic conditions in Europe at the time (Huntley, 1990; Jalut et al., 2000). It is also noteworthy that taxonomic diversity increases towards the top of the sequence (MIR4) (Fig. 3). This is probably the result of a disturbed landscape as a consequence of the pressure of human activities on the environment. The taxa in MIR4 include Fabaceae, *Rhamnus* and *Sambucus*, which are absent in the rest of the sequence. These changes in the abundance of *Quercus*, as well as other taxa accompanying the two wood anatomical types within this genus are related to environmental variations that took place during the middle Holocene. The cause of this variation can most likely be attributed to the intensification of human activities related to agriculture and livestock (grazing), or other exploitation activities (fuel, timber), as well as the climatic variation that occurred during the sub-boreal (Allué and Euba, 2008; Rodríguez and Buxó, 2008). Anthracological and palynological records from other areas show similar patterns, providing evidence of human disturbances and climatic variations throughout the Holocene (Carrión et al., 2003; Allué et al., 2009). Also, human disturbances identified at least during the Neolithic in the palynological record might reflect the sustainable exploitation of forests (Revelles et al., 2014).

Three different dendrological measurements were taken on a small sample of charcoal remains from the El Mirador sequence. The results are encouraging, but provide contradictory data and do not in themselves constitute direct evidence presenting definitive answers to the questions this work explores. Nevertheless, our results clearly indicate a tendency suggesting that the modification of the tree rings may have been caused by the impact of human activities on the woodland.

The ring curvature results show differences in the different levels: they are straighter at the base levels and more curved at the top levels. These results are the opposite of those obtained for the minimum diameter. According to the minimum diameter results, which are reliable, the ring curvature analyses should always indicate *very curved* rings. According to Garcia and Dufraisse (2012) and Paradis-Grenouillet et al. (2013), errors in the measurements for minimum diameter do not significantly alter the results, and this error can be measured and compensated for. To consider errors that might occur in the trigonometry calculation, Garcia and Dufraisse (2012) estimated margins of error caused by the technique and by the volume reduction resulting from carbonization. The results before and after calculating the margin of error were very similar, so the results obtained before calculating the error were considered quite reliable. Furthermore, the authors demonstrated the reliability of this formula in more than 50% of cases. In the case of El Mirador, the fragments were very small and we tried to work with angles (‘a’) and the lengths of the opposing sides (d/2) exceeding 2 mm as proposed by these authors for the reliable use of the formula, but in many cases this was impossible.

According to Garcia and Dufraisse (2012), in fragments smaller than 10 cm, the trigonometry calculation overestimates the values. However, in the few modern samples we analysed, the values are underestimated. These errors could be due to the species or due to pruning causing changes in the wood, making the calculation ineffective. In this respect, more experimental studies are needed to move towards clearly identifying these values and their interpretations (Out et al., 2013).

To check the reliability of the trigonometric method applied to the El Mirador charcoal, we applied the same measurements and trigonometric formulation used on the archaeological material to modern reference material from the collection of different types of wood from the existing oaks at the Sierra de Atapuerca (*Q. faginea* and *Q. pyrenaica*) with a known diameter. In each of the four experimental samples, the radius was measured to obtain an average because the fragments were not completely circular. Subsequently, this average was multiplied by two and compared to the value obtained with the trigonometric formula. The modern samples showed that this calculation accumulated too many errors in the analysed material. In the archaeological samples from El Mirador, these errors could be caused by non-circular branches. Also, the eccentricity of the branch needs to be taken into account, particularly in young individuals. The applied trigonometric formula assumes that the rays meet in the middle; hence a minimal variation in the angle may have led to considerable errors in the final result of the formula.

The results of the minimal diameter should be taken cautiously in these analyses because of possible errors and because of the small sample studied. However, these data are objective and reliable and show a particular growth rate among the remains. This, together with the abrupt change of growth rate that was repeatedly observed in many samples points to human management to obtain small branches and shoots to use as leafy fodder, in addition to other uses. Therefore, we suggest that the features studied here are probably related to human activities.

The characterization of the charcoal record indicates plant communities dominated by deciduous and evergreen oaks. It also suggests that the humans likely had a preference for or made preferential use of oaks, which, overall, and throughout the entire sequence represent over 60% of the sample. The systematic and recurrent use of oaks over the course of the timescale in which the cave was used could indicate the existence of specific exploitation patterns, suggesting forest management or intense activity in the woodland. The archaeobotanical material, including seeds and palynological records, clearly indicate the presence of forests (oaks and pines) and open land related to agriculture and pastures, as well as disturbed lands in the immediate surroundings of the cavity and on a regional scale (Allué and Euba, 2008:; Cabanes et al., 2009; Rodríguez et al., 2016; Expósito, 2016). Palynological data from the El Mirador sequence suggest that on the regional scale a mosaic landscape would have been equally distributed according to biogeography (Expósito, 2016). Therefore, oak forests were important but did not cover the entire landscape. The distribution of oaks was probably much like it is today; deciduous distributed on the terraces (cf. *Q. pyrenaica*) with deeper, more acidic, richer soils, and evergreen (cf. *Quercus rotundifolia*) and some deciduous (cf. *Q. faginea*) on the limestone soils of the Sierra de Atapuerca.

The human groups using the cave probably had a mixed economy and conducted related activities, more or less intensively, inside the cave (crop processing, animal feeding, domestic activities). Thus, the use of land for cultivation and livestock activities during occupations over a long, continuous period of time may have given rise to changes in the landscape. These changes may have had an impact on the physiognomy of the surrounding forests. The dendrological data resulting from the El Mirador samples has provided specific data indicating the presence of changes in wood structure, which suggests that human activities were affecting the woodland. In the first place, data related to the marked reduction in growth might point to the possible pruning of trees. Pruning provides leaves and stimulates rapid regeneration of young branches for fodder for domestic animals, especially during winter, and has already been documented in the Neolithic (Rasmussen, 1990). At El Mirador, the charcoal fragments showing this characteristic also have a high number of rings. According to this analysis, the growth rings were very narrow, in other words, the trees had a rapid rate of growth. The early wood consisted of a single row of pores and the growth rings were very narrow, and late wood rings were also sometimes very narrow or absent. This feature was also observed in the modern samples. These very narrow growth rings indicate a rapid growth rate. If we consider that the fragments analysed came from young individuals, we can suggest that the branches belonged to pruned trees or trees that were consumed regularly. This allows for the regeneration of young branches that could be used as leafy fodder regularly consumed in the cave by livestock. Furthermore, evidence of cultivation, including crop seeds and spikelet forks and weeds in the archaeobotanical assemblage, could be also related to foddering activities. The use of crops as food or for animal feed is difficult to distinguish on the basis of these records (Jones, 1998); however, taking into account that these groups had a mixed economy, both uses are possible.

Furthermore, livestock management has been observed throughout the sequence, indicating patterns related to the exploitation of small herds (Martín et al., 2009; Martín et al., 2016). The zooarchaeological study suggests that the cave was used in winter and early spring during the ovicaprine breeding period and that, in most of the occupations, the cave was used for penning pregnant livestock and breeding (Martín et al., 2016). Additionally, acorn remains are not abundant and are only present in eight of the 18 layers analysed for this study. The absence of acorns or the low numbers of these remains could be interpreted as being related to ecological, taphonomic and behavioural aspects (Zapata et al., 2008; Moreno-Larrazabal et al., 2014). At El Mirador, the number of acorns varies from one to 17 per layer, suggesting that this fruit was not systematically exploited for food and that wood may have been collected in winter or early spring when the fruit had already fallen from the tree. These results are consistent with the anthracological evidence suggesting the specific use of oak forests. Consequently, we might suggest that foddering was one of the main activities carried out in the cave and it was related to livestock breeding. Thus, leafy fodder and crop hay were part of the animal feed used at the site, and included, at the base of the sequence, crops, crop processing remains, deciduous oaks, *Fraxinus* and Maloideae. The data also suggest an intense exploitation of oak forests, and considerable evidence points to the possible systematic exploitation of small twigs.

During the Atlantic period, pollen sequences indicate a considerable extension of forested areas due to increasingly favourable climatic conditions (Peñalba, 1994; Sanchez-Goñi and Hannon, 1999; Ruiz-Zapata et al., 2002). The lack of open land with pastures would have favoured the development of forest management strategies in order to increase leafy-hay productivity. The increase of open land due to human disturbances might have changed this pattern by the middle Neolithic. However, there is no clear evidence of these changes, and forest management for different purposes could form part of human activities throughout the Neolithic and the Bronze Age. Ethnographic studies among the Plikati communities in Greece clearly show how deciduous oaks are shredded for winter hay (Halstead et al., 1996). In the mountainous areas of Iberia, there is a long history of activities related to pastoralism with a mixed economy, and numerous caves have been used as pens (Bergadà, 1998; Badal, 1999; Angelucci et al., 2009; Polo et al., 2014). The anthracological records from these sites contain considerable numbers of species that were most likely used for leafy fodder as well as for fuel (Badal, 1999; Peña-Chocarro et al., 2005; Allué et al., 2009; Moreno-Larrazabal et al., 2014). However, the identification of direct evidence in the charcoal assemblages definitively establishing forest management strategies associated with this activity remains a challenge.

6. Conclusion

The anthracological and dendrological assemblage from El Mirador suggests intense human activity throughout the entire sequence that affected the physiognomy of the surrounding forest. These activities are not only indicated by these data, but are also documented by means of all the evidence left by the human groups that occupied El Mirador cave. The evidence points to the transformation of forests resulting from agricultural activities, but also related to forest management activities focused on the exploitation of oaks for use as winter fodder. The usefulness of dendrological analyses with small fragments of charcoal remains rather limited, and experimental work on reference material is required to make progress in this field.

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