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1 DENDRO-ANTHRACOLOGICAL TOOLS APPLIED TO SCOTS TYPE PINE

2 FORESTS EXPLOITATION AS FUEL DURING THE MESOLITHIC-3 NEOLITHIC TRANSITION IN THE SOUTHERN CENTRAL PRE-PYRENEES

- 4 (**SPAIN**).
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- 18 Keywords: *Pinus sylvestris* tp., Early-Middle Holocene, firewood procurement,
 19 dendro-anthracology, anthraco-typology, charcoal analyses, referential datasets, NE
 20 Iberia.

21 Abstract

This work focuses on the reconstruction of fuelwood procurement during the 22 Mesolithic-Neolithic transition in the southern central Pre-Pyrenees (Spain). The study 23 combines wood charcoal identification with the application of dendro-anthracological 24 approaches in the archaeological sequence of Esplugón (9.4-6.8 kyr cal BP) 25 (Sabiñanigo, Huesca). Scots type pine (Pinus sylvestris tp.) reaches in this record 26 around 90% of exploited firewood in line with its abundance in the inner Iberia 27 mountainous areas during the onset of the Holocene. The classification of pine wood 28 fragments in anthraco-groups is based on the combination of different dendro-29 30 anthracological tools: i) pith location tool and wood diameter estimation based on the 31 trigonomethric method tool (ADmodel), ii) the study of growth rate based on the annual 32 tree-ring width measurements, and iii) a modern dendrological dataset. There are 33 hardly any differences observed in firewood procurement between the last huntergatherers and the first farmers in the long sequences from rock-shelters with recurrent 34 35 human occupations. First results from this site point to the exploitation of whole trees but a high use of small pine branches probably from the gathering of branch shedding. 36

37

38 1. INTRODUCTION

This work constitutes a holistic approach to Early-Middle Holocene archaeological 39 wood charcoal assemblages from the southern central Pre-Pyrenees (Spain). Some of 40 these assemblages are characterized by a very homogeneous composition, in which 41 42 Scots type pine wood (*Pinus sylvestris* tp.) always reaches very high values, > 70%, despite the taxonomic diversity of the anthracological samples. Scots type pines (Pinus 43 sylvestris tp.) have played an important role in Mediterranean vegetation since the 44 Pleistocene which is reflected in their ubiquity presence in several wood charcoal 45 assemblages of southern Europe (Alcolea, 2015; Alcolea et al., 2017a; 2017b; Allué et 46 al., 2012, 2017a; 2017b; 2018; Allué and Mas, 2020; Aura et al., 2005; Badal et al., 47 48 2012a, 2012b; Badal and Martínez-Varea, 2018; Carrión et al., 2008; 2019; Mazo and Alcolea, 2019; Montes et al., 2016; Rubiales et al., 2010; Théry-Parisot, 2001; 2002; 49 50 Théry-Parisot and Thiébault, 2005; Théry-Parisot et al., 2016; 2018; Vidal-Matutano, 2017; Vidal-Matutano et al., 2015, 2017, 2018). 51

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Pinus sylvestris L. forests show a wider world distribution area nowadays although in 53 the Iberian Peninsula they are now restricted to the highest elevations in mountain areas 54 (Costa et al., 2001). They are accompanied by Pinus nigra subsp. salzmannii (Dunal) 55 Franco in the lowlands and *Pinus mugo* subsp. uncinata (Ramond ex DC.) that 56 dominates the highlands. Unfortunately, these species can hardly be distinguished on 57 the basis of their microscopic wood anatomy, so they are grouped under the taxon *Pinus* 58 sylvestris tp. which refers to all these cryophillous pines that abound in the 59 Mediterranean mountains. 60

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The abundance of Pinus sylvestris tp. wood in certain archaeological records for 62 63 thousands of years implies an evident limitation in the interpretation of the archaeological record from the point of view of standard wood charcoal analysis. 64 65 However, the large amount of available fragments from the same taxon also presents an opportunity to apply innovative anthracological and dendro-anthracological tools to the 66 67 study of these anthracological contexts (Allué et al., 2009; Allué and Mas, 2020; Caruso-Fermé and Théry-Parisot, 2018; Caruso-Fermé et al., 2013; Dufraisse, 2006; 68 69 Dufraisse and García-Martínez, 2011; Dufraisse et al., 2017; 2020; García-Martínez and 70 Dufraisse, 2012; Henry and Théry-Parisot 2014; Paradis-Grenouillet et al., 2013; Thèry-

Parisot et al., 2011; Théry-Parisot and Henry, 2012; Vidal-Matutano et al., 2017).

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73 In this paper, the previously unpublished wood charcoal analysis of the entire 74 archaeological sequence of the Esplugón site (Huesca, NE Iberia) is presented in its regional context. In addition, we introduce the quantitative study of the wood charcoal 75 76 alterations, as well as the first results of the application of dendro-anthracological tools to wood charcoal fragments, which permit reconstructing which parts of the plants were 77 78 exploited. For the latter, it has been necessary to create a specific modern dendrological dataset for Scots type pines (Pinus sylvestris tp.) in the south central Pre-Pyrenees. All 79 these approaches enable a better global understanding of forest management by the 80 human inhabitants of the site. The archaeological sequence of Esplugón, including 81 succesive Mesolithic and Neolithic occupations, allows a comparison of fuelwood 82 procurement between the last hunter-gatherers and the first farmers in this region. This 83 84 work constitutes a starting point for future wood charcoal studies in Pleistocene and Holocene sequences from NE Iberia. 85

86

87 2. REGIONAL SETTING AND SITE DESCRIPTION

The southern central Pre-Pyrenees represent a key region for understanding the 88 Mesolithic-Neolithic transition in NE Iberia. The Pyrenean foothills, or Pre-Pyrenees 89 (450-950 m asl), comprise human occupations in rock-shelters and caves, some of them 90 containing long sequences of prehistoric occupation, such as Esplugón, Forcas, Artusia, 91 Aizpea and Arba de Biel sites (Utrilla et al., 2016, Obón et al., 2019; Utrilla and Mazo, 92 93 2014; García-Martínez de Lagrán et al, 2017; Barandiarán and Cava, 2001; Montes et al., 2016; Laborda, 2019) (Figure 1). All sites have many similarities as they contain 94 95 recurrent and probably short-term occupations and they are strategically located over the valley, controlling both human and prey movements. Wood charcoal analysis has been 96 recently performed in all of them (Zapata, 2001; Alcolea, 2015; Montes et al., 2016; 97 98 García-Martínez de Lagrán et al, 2017).

99 Esplugón is the largest rock-shelter in the southern central Pyrenees known so far for 100 this chrono-cultural period (Figure 2). It is located in the middle transverse corridor of 101 the Guarga valley (Huesca, NE Iberia) between the Pre-Pyrenees and the Pyrenees. The 102 description of six Mesolithic and Neolithic archaeological layers makes it a reference

site for understanding the Neolithisation process in the Ebro basin (NE Iberia) (Utrilla et
al., 2012; 2016; Berdejo and Obón, 2013; Berdejo et al., 2018; Obón et al., 2019).
Seven archaeological layers have been identified (numbered 1-7 from top to bottom)
organized in 4 chrono-cultural stages of prehistoric occupation (Figure 3):

- Stage 1. Layer 1. A partially disturbed Chalcolithic layer, which contained both
 Chalcolithic and historical materials.
- Stage 2. Layers 2 and 3 sup. An Early Neolithic (EN) occupation, in which
 geometric microliths with abrupt retouching was recovered, as well as occasional
 bone tools and pottery fragments with incised and cardial decorations.
- Stage 3. Layers 3 inf. and 4. A Late Mesolithic (LM) or Geometric Mesolithic
 occupation, in which a rich lithic assemblage of geometric microliths was recovered,
 with triangles in the earlier phases and later on trapezes.
- Stage 4. Layers 5 and 6. An Early Mesolithic (EM) occupation which still lacks an
 accurate chrono-cultural definition. Although the occasional lithic materials
 recovered seem to fit with a Notches and Denticulate Mesolithic (layer 5) and a
 Microblade Epipaleolithic (layer 6), the available radiocarbon dates do not support
 the Epipalaeolithic attribution.

14 radiocarbon dates (Table 1 and Figure 4) place the occupation of the site (excluding
Stage 1) between 9.4 and 6.8 ka cal BP (Obón et al., 2019; Laborda, 2019). The Early
Mesolithic (EM) stage occurs during the last millennium of the Early Holocene (9.4-8.5
ka cal BP). The start of the Geometric Mesolithic or Late Mesolithic (LM) stage
coincides with the 8.4 and 8.2 arid events that give rise to the Middle Holocene in the
region (8.5-7.5 ka cal BP). Finally, the Early Neolithic (EN) stage occurs during the
Middle Holocene (7.3-6.8 ka cal BP).

127 Archaeological materials recovered at the site as well as the preliminary archaeozoological results suggest that hunting was the main focus of the settlement 128 throughout the excavated sequence. Recurrent short-term occupations are proposed for 129 the Mesolithic whilemore or less stable, long-term occupations involving various 130 activities (scraping, drilling, mowing) besides hunting, have been proposed for the 131 Neolithic (Utrilla et al., 2016; Obón et al., 2019). In any case, the hunted species are 132 characteristic of a forested environment dominated by red deer (Cervus elaphus), roe 133 134 deer (*Capreolus capreolus*), and wild boar (*Sus scrofa*) (Obón et al., 2019). Despite the presence of some domestic animals only in layer 2, neither traces related to livestock 135

sheltering and feeding nor storage structures have been found so far at the site (Laborda,2019).

Esolugón is located at 800 m asl. This area is currently characterised by a continental 138 Mediterranean climate with long, dry summers, an average annual temperature between 139 140 12°C and 14°C, and 500 mm of annual precipitation. The vegetation is characteristic of the transitional zone between the meso-Mediterranean and the oro-Mediterranean 141 142 biogeographic zones (Rivas Martínez, 1982). Present-day vegetation is influenced by 143 the altitudinal gradient, relief, calcareous lithology and the high levels of human impact. 144 Vegetation around the site is dominated by degraded forest of deciduous Quercus (Quercus faginea Lam. and Quercus cerrioides Wilk & Costa). Scots pine (Pinus 145 146 sylvestris L.) and mainly extensive plantations of Austrian pine (Pinus nigra subsp. laricio Maire) grow throughout the valley. Boxwood (Buxus sempervirens L.), 147 148 hawthorn (Crataegus monogyna Jacq.), dogwood (Cornus sanguinea L.), and brooms 149 (Echinospartum horridum (Vahl) Rothm), grow abundantly in the scrubland and forest edges. The proximity of the Guarga river defines the ample presence of riparian 150 151 vegetation dominated by black poplar (Populus nigra L.) and willow (Salix eleagnos Scop.). 152

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3. Materials and methods

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156 *3.1. Materials.*

157 Archaeological works started in 2009. Specific strategies of sampling and recovery for 158 archaeobotanical remains have been followed at Esplugón site during the 2012, 2013 159 and 2017 fieldwork seasons. Archaeological layers are characterized by high density 160 and good preservation of charred wood remains. Hand-picking of visible charcoal 161 remains found during fieldwork was accompanied by the wet sieving of all the excavated sediment through a 2-1 mm mesh. Also, flotation tests with a 0,5-0,25 mm 162 mesh of 20 litres of sediment per square meter and archaeological layer were performed 163 by M. Alcolea in the Laboratory of Prehistory of the University of Zaragoza in 2018. 164 No carpological remains have been found so far in the sampled archaeological deposit. . 165 Charred wood identified in this work corresponds to scattered charcoal in the sediment 166 167 from samples recovered by hand-picking, wet sieving and flotation. Scattered charcoal is the result of consecutive combustion events reflecting successive collections of 168

firewood (Chabal, 1997). It constitutes a valuable source of information about the
surrounding vegetation of the site and the activities of human groups in the past (Chabal
et al., 1999; Théry-Parisot et al., 2010).

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173 *3.2. Methods.*

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175 *3.2.1.* Wood charcoal analyses.

Wood charcoal fragments were analysed following the standard methods in 176 anthracology (Vernet, 1973). For the taxonomic identification the wood anatomical 177 features of each fragment were observed along the three anatomical planes under 178 179 magnifications between x50 and x600, using an incident light dark/bright field Leica DM2700M microscope at the University of Zaragoza (Spain). Botanical identifications 180 181 were made by reference to wood anatomy atlases (Schweingruber, 1990, García Esteban et al., 2003) and modern carbonized wood reference specimens. Nomenclature follows 182 the guidelines in *Tela Botanica* (https://www.tela-botanica.org/). No significant 183 differences in the number of identified taxa have been documented from the screened 184 and floated samples. 185

186

187 *3.2.2. Charcoal preservation and condition of wood.*

Charcoal taphonomy in anthracological research provide additional information about 188 plant growth, wood-gathering strategies and combustion and post-deposition processes 189 (Marguerie and Hunot, 2007; Théry-Parisot et al., 2010). In this study 4 relevant 190 features were recorded as absent or present: cell collapse, compression wood, radial 191 192 cracks and vitrification (Braadbaart and Poole, 2008; McParland et al., 2010; Moskal del Hoyo et al., 2010; Thèry-Parisot and Henry, 2012; Henry and Théry-Parisot, 2014; 193 194 Vidal-Matutano et al., 2017; Caruso-Fermé and Thèry-Parisot, 2018; Allué and Mas, 2020; Courty et al., 2020). These features in archaeological charcoals provide relevant 195 196 information about the condition of the procured firewood as well as some conditions of 197 the combustion process. Preservation factors also actually affects wood charcoal 198 stucture preservation and therefore the possibilities in the application of dendro-199 anthracological techniques.

200 *3.2.3. Dendro-anthracological techniques.*

Dendro-anthracological tools allow measuring dendro-anthracological parameters based 201 202 on morpho-anatomical criteria (Table 2). Dendro-anthracological techniques have been applied on selected Pinus sylvestris tp. wood charcoal fragments with the aid of a 203 multizoom microscope (Nikon AZ100) that allows magnification factors from x4 to 204 205 x500 and the NIS Element image analysis software. The measurements are based on the 206 distance and the angle between two ligneous rays. They were obtained by using a semi-207 automatic system based on 4 landmarks integrated in the Nikon NIS Elements software. All measurements are taken in transverse (or cross) plane. The selection of fragments 208 was based on two criteria: size and preservation status. In terms of size, a minimum of 4 209 mm^2 is required in transverse (or cross) plane. Regarding the preservation status, the 210 microscopic wood anatomical features must not be deformed, particularly the ligneous 211 212 rays and the growth ring boundaries.

213 *3.2.3.1. The pith location tool and wood diameter estimation.*

214 Pinus sylvestris tp. is an appropriate taxon to apply dendro-anthracological techniques. Regarding microscopic wood anatomy features, the presence of visible ligneous rays 215 allow measuring the charcoal pith distance by applying the trigonometric method 216 (Dufraisse and García-Martínez, 2011; Paradis-Grenouillet et al., 2013). It is also 217 important that a modern reference dataset is available for measuring the caliber of pines 218 219 in the framework of the DENDRAC project (http://dendrac.mnhn.fr/) (Dufraisse et al., 2020). The pith location tool is used to measure the distance between the charcoal 220 fragment and the theoretical location of the missing pith. This tool is based on 221 measurements of the angle and the distance between two ligneous rays and the 222 application of correction factors (Dufraisse and García-Martínez, 2011; Dufraisse et al., 223 2020). The angle must be > 2 degrees and the distance > 2 mm for reducing the margin 224 of error and improving results in dendro-anthracological applications (Dufraisse et al., 225 226 2017; 2020). The values were ordered into diameter classes chosen to be compatible with the standards used in dendrometrical plans by foresters: 4 cm, 7 cm and 20 cm but 227 adding some wood cuts. For conifers diameter classes chosen are [0-2] cm, [2-4] cm, [4-228 7] cm, [7-10] cm, [10-14] cm, [14-20] cm and >20 cm (Dufraisse et al., 2017). 229

230

231 *3.2.3.2. The Analysis Diameter model (ADmodel).*

The Analysis Diameter model has been developed as a tool dedicated to recomposeunburnt wood diameter (UWD) in terms of volume based on the distribution of diameter

classes obtained with the pith estimation tool (Dufraisse et al., 2017). It was developed, 234 based on the fact (i) burnt, wood undergoes both mass loss and charcoal fragmentation 235 and (ii) a trunk is biologically considered to be a stack of hollow cones whose thickness 236 corresponds to the amplitude of the diameter classes (Dufraisse, 2006; Dufraisse and 237 238 García-Martínez, 2011). A calculation table provides the respective distribution of these cones in terms of volume (Dufraisse et al., 2020). This model does not reconstruct the 239 original quantity or volume of burnt wood (Dufraisse and García-Martínez, 2011, 240 241 Dufraisse et al., 2017).

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243 *3.2.3.3. Tree-ring analysis and growth rate.*

Pinus sylvestris tp. wood is characterized in the transverse (or cross) plane by distinct 244 growth ring boundaries (occasionally generating false growth rings in samples from 245 lowlands) and generally abrupt transition from early- (EW) to latewood (LW) 246 (Schweingruber, 1990; Schoch et al., 2004). It makes *Pinus sylvestris* tp. an appropriate 247 248 taxon for measuring tree-ring and EW width. Both has been measured in mm with the NIS Element image analysis software (Nikon AZ100). Correction factors have been 249 250 applied to reverse shrinkage effect in the tree-ring width during charring (García-Martínez and Dufraisse, 2012). The results were plotted by R software (R Core Team, 251 252 2017).

In order to establish a discriminating threshold between slow growth rate and fast 253 growth rate we have built a modern dendrological reference dataset in the southern 254 central Pyrenees. Trunks and branches of three Pinus sylvestris L. (and three Pinus 255 nigra subsp. laricio Maire) adult trees between 40 and 50 years old from the Station 1, 256 257 called Secorún (UTM 30T 734715 469813, 1047 masl), close to Esplugón, were sampled (Figure 1). Our goal was to know the intra-individual variability and establish 258 259 the existence of different growth patterns between trunk and branches within the same tree. Trunk core discs were sampled at breast height, 1.30 m above ground, as is 260 261 standard in dendrochronology. Apical trunks are sampled at an average height of 10.5 m at which they have a similar diameter to the sampled branches. Four primary branches 262 263 regularly located along the trunk height have been sampled and measured for each tree. The samples have been measured to the nearest 0.01 mm with the TSAP-Win program 264 265 and LINTABTM (Rinntech, Heidelberg, Germany) (Rinn, 2011).

266 *3.2.4. Anthraco-typological classification*

The combination of these dendro-anthracological parameters permits the classification 267 of fragments in four anthraco-groups based on the relationship between the estimated 268 minimum diameter and the growth rate (Dufraisse et al., 2017). Following the foresters' 269 diameter ranking, values <7 cm were considered to represent branches, and values >7 270 cm were considered mature or young trunks. This is the threshold used in this work 271 even though in the case of archaeological charcoal fragments, projected diameters <7272 273 cm could correspond to both branches and young individuals (Picornell-Gelabert and Dufraisse, 2018). Regarding growth rate, the threshold between slow growth and fast 274 growth in this work has been established in 1 mm based on the modern dendrological 275 reference dataset created at the Station 1 Secorún (Figure 5). An anthraco-typological 276 key to sort Pinus sylvestris tp. archaeological charcoal fragments into 4 anthraco-groups 277 is proposed (Figure 6) following Dufraisse et al., 2017 for deciduous oak. Following 278 these assumptions, the anthraco-group 1 corresponds theoretically to the exploitation of 279 branches while anthraco-groups 2, 3 and 4 represent to the exploitation of trunks. The 280 281 group 2 would correspond to the inner part of the trunk while groups 3 and 4 to the outer part (see also Picornell-Gelabert et al., same volume). 282

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284	4. Results
284	4. Kesults

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286 *4.1. Taxonomic diversity.*

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We have studied 1,480 wood charcoal fragments from 6 archaeological layers (Table 3). 288 The presence of 7 taxa has been documented: ash (Fraxinus sp.), juniper (Juniperus 289 sp.), Scots pine type (Pinus sylvestris tp.), deciduous oak (Quercus sp. deciduous), holm 290 oak (Quercus sp. evergreen), and thorny shrubs belonging to the Rosaceae family 291 292 (Rosaceae/Maloideae and *Prunus* sp.). The reported percentages of Scots pine type wood vary between 75 and 100% of the identified fragments in the different 293 archaeological layers (Figure 7). Based on the total number of determined fragments at 294 295 the site, pine reaches 91%, followed by oak that reaches 6.7% while the remaining taxa comprise c. 2.3%. The high frequency of pine is common in anthracological 296 assemblages from rockshelters in the region during the entire timespan covered by the 297 298 Esplugón sampled stratigraphy.

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300 *4.2.* Condition of wood.

Relevant features recorded in this study: cell collapse, compression wood, radial cracks
and vitrification, entail high percentages in the anthracological assemblage of Esplugón
(Table 4 and Figure 8). They are common alterations in archaeological charcoals.

Cell collapse is commonly associated with decayed or rotten wood caused by fungi and xylophagous insects (Moskal del Hoyo et al., 2010; Henry and Théry-Parisot, 2014; Vidal-Matutano et al., 2017) or chemical and physical alterations that affect deadwood (Allué and Mas, 2020). A high number of fragments shows signs of fungal degradation, affecting34.9-58.6% of pine charcoal fragments. This alteration inhibits the application of dendro-anthracological techniques to fragments in which an important part of the transverse surface is affected by this parameter.

Compression wood is associated with a loss of verticality in stem growth. In mountain environments, it can affect both branches and trunks growing on acute slopes, thus it cannot be used as a discriminating factor. Reaction wood reaches from 25.2 to 69.6% of the pine charcoal fragments. These fragments have been ommited from dendroanthracological analysis even though correction factors may reduce the influence of offcentred piths (Dufraisse et al., 2017; 2020).

317 The presence of radial cracks on the transverse plane affects 5.6-20% of pine charcoal fragments. They are very common in charred wood because of the loss of volatile 318 319 compounds during the combustion process. Proposed as evidence of the use of green wood as fuel, it has been demonstrated that the occurrence of radial cracks is not 320 correlated with moisture content (Thèry-Parisot and Henry, 2012; Caruso-Fermé 321 and Thèry-Parisot, 2018) being probably important other volatile compounds, e.g. 322 323 resins, which are common in Scots pines type. Its presence could affect and deform ray 324 distance and angle. Heavily affected pine charcoal fragments have been also omitted 325 from dendro-anthracological analysis.

Finally, vitrification affects 3.2-24.4% of pine charcoal fragments. It is the main cause of the high number of fragments that could not be determined (classified as undeterminable; see table 3). Although in the current state of the research the causes of this feature are not known (Braadbaart and Poole, 2008; McParland et al., 2010; Courty et al., 2020), it is related to the combustion process. It is especially usual in conifers, probably associated with some specific compounds as resins. The high presence of

reaction wood, which increases the lignin in tracheid cell walls, a thermoplasticcompound, could also favour the vitrification of wood (Alcolea, 2017).

4.3. Minimum calibres of exploited stems.

Charcoal preservation and condition of wood have strongly conditioned the application 335 of dendrometric tools. Although only 199 pine charcoal fragments met special 336 requirements of size and preservation status, there are evenly spread across the different 337 338 phases (Table 5). Both 2 Mesolithic (n=155) and Neolithic (n=44) stages are wellrepresented in the subsample. Trigonometric method has been applied to estimate 339 340 minimum calibres of exploited firewood. Diameter classes for each stage have been established on the base of minimum diameters of each fragment using pith location tool 341 342 and wood diameter estimation (Table 5). The UDW has been recomposed using the 343 Analysis Diameter model (ADmodel) (available in https://dendrac.mnhn.fr/spip.php?article237) (Dufraisse et al., 2020). 344

At the Esplugón site, the exploitation of small calibres predominates throughout the entire archaeological sequence. Minimum diameter classes between 4 and 7 cm predominate during the 2 Mesolithic stages (EM and LM). During the Early Neolithic (EN) this diameter class diminishes while the diameter classes between 2 and 4 cm and 7 and 10 cm gain importance. Above 10 cm of diameter few fragments have been documented (Table 5). Recomposed percentages (AD%) reinforce the observed tendency.

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Usually, the diameter classes <7 cm correspond to branches and/or the inner part of the trunks, and the diameter classes >7 cm correspond to the outer part of the trunks (Deleuze et al., 2014). This assertion was tested and confirmed on *Pinus halepensis* (Picornell et al, same volume). However, the class between 7 and 10 cm of diameter, considered as a transition, is difficult to classify in this scheme. To discriminate the parts of the exploited stems it is necessary to combine minimum calibres with the growth rate of tree-rings

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361 *4.4. Growth rate.*

Growth rate has been calculated in 199 pine charcoal fragments by measuring growthring width. A total of 1,788 growth ring width has been measured and the average value

has been calculated to obtain growth rate of each charcoal fragment. Results show
calibrated values after applying correction factors (García-Martínez and Dufraisse,
2012).

No major differences in growth rate have been documented among the different stages (Figure 9). Organizing growth ring width by diameter classes it can be observed that average values are higher in the diametrer classes >10 cm. Wider growth rings are documented in the 2 to 4 and 4 to 7 cm diameter classes but they always constitute outlier values (Figure 10).

The results of dendrological analysis of the modern dendrological reference dataset from Secorún show clear intra-individual differences in growth rate between trunks and branches from the same tree and are reproduced in all sampled individuals (Figure 5). According to these data, the threshold between slow and fast growth rate has been established in 1 mm. Archaeological pine charcoal fragments that present average growth ring width values < 1 mm are considered as slow growth rate and those that present values > 1 mm, as fast growth rate.

379 *4.5.* Anthraco-typological classification: the exploited parts of plants.

Anthraco-typological classification of the studied anthracological assemblage combines 380 the estimation of the minimum calibres and the growth rate (Dufraisse et al., 2017). The 381 199 pine wood charcoal fragments have been classified in 4 groups (Table 6). The 382 383 anthraco-type 1, that theoretically correspond to branches, has the largest number of fragments in the 3 studied stages, reaching almost 80% during the Early Mesolithic 384 (EM) and 70% during the Late Mesolithic (LM) and Early Neolithic (EN). The 385 anthraco-types 2, 3 and 4, that theoretically correspond to different parts of the trunk, 386 represent lower percentages, reaching 20% during the Early Mesolithic (EM) and 387 388 almost 30% during the Late Mesolithic (LM) and Early Neolithic (EN).

389 5. Firewood procurement in the southern central Pre-Pyrenees during the Early390 Middle Holocene

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392 *5.1. Floristic composition of the forest: taxonomic analyses.*

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394 *5.1.1. Early Mesolithic (9.4-8.5 kyr cal BP)*

395

During the Early Mesolithic occupation in Esplugón, the Pinus sylvestris tp. is the 396 preferred wood for fuel with values reaching up to 90%. Even though extremely high 397 values of conifers persist at the onset of the Holocene in the southern central Pyrenees 398 in both lowland and high altitudes, pollen lake records suggest the rapid spread of 399 mesophytes in the low montane bioclimatic zone, mainly deciduous Quercus, after ca. 400 9.5 kyr cal BP due to increases in temperature, warmer summers and an increase in 401 402 water availability (Pérez-Sanz, 2014; González-Sampériz et al., 2017). These are present in the anthracological record of Esplugón in low frequencies. Deciduous and 403 evergreen Quercus hardly represent 3% of identified wood charcoal fragments in layer 6 404 and 7% in layer 5. Shrubby taxa typical of forest edges (Juniperus sp., Prunus sp., 405 Rosaceae/Maloideae) complete the list also reaching low values in the layer 6 and 406 disappearing in layer 5. 407

408

Other Pyrenean anthracological sequences show similar patterns: *Pinus sylvestris* tp. prevails in low montane assemblages until ca. 8.5 kyr cal BP as indicated by the anthracological assemblages from Forcas (Alcolea, 2015), Artusia (García-Martínez de Lagrán, 2017) and the Arba de Biel sites (Montes et al., 2016). At the lowlands, Scots type pine forests are replaced by thermophilous Mediterranean pines from ca. 8.7 kyr cal BP (Alcolea et al., 2017a).

415

416 5.1.2. Late Mesolithic (8.5-7.5 kyr cal BP)

417

After 8.2 kyr cal BP pollen lake records indicate that semi-deciduous and evergreen *Quercus* replaced mesophytes in the lowlands and low montane (González-Sampériz et al., 2017). Simultaneously, these deciduous forests replaced pinewoods also in the high montane and subalpine bioclimatic zones (Plà and Catalán, 2005; González-Sampériz et al., 2005; Pérez-Sanz et al., 2013) indicating a relevant increase in winter temperatures and a shift in the precipitation regime with a more evenly distributed rainfall (Magny et al., 2002; Morellón et al., 2009).

Pinus sylvestris tp. persists as the most consumed wood for fuel in Esplugón during its
Late Mesolithic occupation in layers 4 and 3 inf. between 8.5 and 7.5 kyr cal BP.
Accompanying taxa are basically the same as in the previous period and they do not
reach 10 % of wood charcoal fragments. The only novelty is the presence of riparian

vegetation represented by a single charcoal fragment of ash (*Fraxinus* sp.). This resilient
tendency of low montane pine forests in the southern central Pyrenees is also supported
by the anthracological records of Forcas (Alcolea, 2015) and Arba de Biel sites (Montes
et al., 2016). On the contrary, the human use of widespread deciduous forest is welldocumented in south eastern Pyrenean deposits (Zapata and Peña-Chocarro, 2005; RuízAlonso and Zapata, 2017).

435 5.1.3. Early Neolithic (7.3-6.8 kyr cal BP)

Despite the chronological gap in the sequence suggested by radiocarbon dating (7.5-7.3 436 kyr cal BP) Pinus sylvestris tp. continues being the most consumed wood for fuel in 437 Esplugón, reaching up to 90% in layer 3 sup. and 75% in layer 2. On the contrary, Pinus 438 439 sylvestris tp. has completely disappeared in the eastern Pyrenean sequences at 7.3 kyr 440 cal BP, mainly replaced by deciduous Quercus and yew (Taxus baccata) accompanied by shrubby taxa (Ruíz-Alonso and Zapata, 2017). The Neolithic deposit of Esplugón 441 just start showing a trend towards the use of deciduous taxa in layer 2, dated to 6.8 kyr 442 cal BP, where deciduous Quercus reaches almost 20% accompanied by all the 443 aforementioned taxa. Resilience of Scots type pinewoods at Esplugón is supported by 444 other wood charcoal analyses in southern central Pyrenees from the low montane (Heinz 445 y Vernet, 1995; Alcolea, 2015; Alcolea et al., 2017b; Montes et al., 2016) to the 446 subalpine bioclimatic zones (Obea et al., 2011; Obea, 2014) at least until 6 kyr cal BP. 447 The limited presence of other taxa in the anthracological record could be related to the 448 structure of pine forests with low shrubby undergrowth (Allué et al., 2018). 449

450 5.2. *Structure of the forest: dendro-anthracological insights.*

451

- 452 5.2.1. The exploited parts of plants.
- 453

454 *Pinus sylvestris* tp. is the main taxon exploited for fuel throughout the archaeological 455 sequence of Esplugón and also in other short-term human occupations in rockshelters, 456 like Forcas (Alcolea, 2016) and the Arba de Biel sites (Montes et al., 2016) suggesting 457 that this woody taxon is the most available in the immediate vicinity of the sites. Even 458 though the resilience of Scots type pine forests has been proposed in some inland 459 regions of Mediterranean Iberia until ca. 7.7 kyr cal BP (Rubiales et al., 2010; Aranbarri 460 et al., 2014) or even during the whole Middle Holocene (8.2-4.2 kyr cal BP) (Franco

Múgica et al., 2001; 2005) due to the delayed onset of the interglacial conditions based 461 on high continentality, water shortage and absence of well-developed soil (Carrión et 462 al., 2010), regional pollen data in the southern central Pyrenees point to a retreat of 463 Scots type pine forests from 9.5 kyr cal BP, more evident after 7.3 kyr cal BP 464 (González-Sampériz et al., 2017). Wood charcoal analysis at Chaves (7.6-7.0 kyr cal 465 BP) reveals the use of a broad spectrum of woody taxa as expected in a long-term 466 settlement where diversified human activities took place (Utrilla and Laborda, 2018). 467 Although Scots type pine is the most consumed taxon it only reaches 30% at level Ib 468 469 (7.6-7.3 kyr cal BP) (Alcolea et al., 2017b).

470

Regarding the parts of exploited plants, no big differences have been documented 471 between the different stages of human occupation. The use of branches, between 70-472 80%, prevails over the use of trunks, between 20-30% throughout the entire 473 archaeological sequence (Figure 11). The arrival of the Neolithic does not introduce a 474 475 change in forest management strategies. This is consistent with the documented uses of the rockshelter. The main human activity is always the hunting of the forest wild species 476 477 like roe deer (Capreolus capreolus), red deer (Cervus elaphus) and wild boar (Sus scrofa) (Obón et al., 2019). Domestic animals are restricted to layer 2 and neither 478 479 storage structures nor stabling layers implying chages in the site function have been 480 found (Laborda, 2019).

481

482 5.2.2. Scots type pine forests exploitation as fuel.

The three native species of cryophillous montane pines growing in NE Iberia are 483 normally grouped in the taxon Pinus sylvestris tp. Montane Iberian pines include Pinus 484 sylvestris L., Pinus mugo subsp. uncinata (Ramond ex DC.) Domin, Pinus nigra subsp. 485 486 salzmannii (Dunal) Franco. Theoretically they grow nowadays at different altitudes in NE Iberia: Pinus nigra between 500 and 800 masl, Pinus sylvestris between 800 and 487 1700 m a.s.l. and *Pinus uncinata* above 1800 masl (Costa et al., 2001), but usually they 488 overlap biogeographically and can interbreed (Quézel and Médail, 2003). These trees do 489 not show differences in wood anatomy allowing to identify each of them (Greguss, 490 1955; Schweingruber, 1990) so its past distribution at species level is not well-known 491 492 (Roiron et al., 2013 Allué et al., 2018). Likewise, is not possible to know if our deposits

493 contain more than one species of Scots type pine. In any case, they share494 biogeographical parameters and tree architecture.

495 We propose that the architecture of Scots type pines strongly influences their use as 496 firewood. The architecture of the tree is characteristic of each species and allows to 497 understand its growth strategy and occupation of the space. Scots type pine trees present a monopodial structure composed of a single stem or trunk that reaches up to thirty 498 499 metres. The trunk is generally straight but it can present alterations due to the ecological 500 conditions of its growth (strong winds, the weight of the snow, the extreme dryness or 501 slope angle). The primary branches grow in polycyclic crowns, formed annually at the 502 same level around the trunk parallel to each other and displaying similar calibres. These 503 trees are characterized by a strong apical dominance, meaning that the branches develop 504 more slowly than the trunk (Riou-Nivert, 2001).

Scots type pine forests have a pyramidal or conical shape when young, which 505 nevertheless changes with age. The silouette of adult trees can vary depending on 506 whether they grow isolated or in groups (Figure 12). When they grow isolated generally 507 green branches reach the foot of the tree. When they grow in groups, these trees exert 508 competition over each other at two levels: (i) in the soil, which affects their radical 509 510 underground system, and (ii) in the air, which affects their radical air system, that is, the branches. In the first case, they "run away" from each other, moving as far as possible to 511 take advantage of soil moisture, giving rise in general to open forests. In the second 512 513 case, they "run away" seeking to reach a greater height to have more access to light. The 514 growth in population provides a lateral shelter, that results in thinner branches and a reduced growth in diameter of the trunk (Riou-Nivert, 2001). In this case, the lower 515 516 branches under cover usually die due to lack of light. There is very little physiological connection between branches and trunk (Shigo et al., 1987). When they are no longer 517 518 functional, a resinous partition isolates them to protect the trunk from infections. The 519 branch becomes parasitic and stops participating in the life of the tree. When the process 520 of decomposition by microorganisms is advanced the branch falls according to the phenomenon known as branch shedding (or natural pruning). This observation is 521 522 supported by the high percentages of decayed wood documented in the record (Figure 8), which are associated with the use of deadwood as fuel (Allué et al., 2009; Henry and 523 524 Thèry-Parisot, 2014; Vidal Matutano et al., 2017).Different palaeoenvironmental and cultural factors has been previosly proposed in the preferential use of *Pinus sylvestris* 525

tp. as fuelwood by European hunter-gatherer groups. The significant mobility of human 526 groups, resulting in seasonal occupations of the sites, and a relatively limited tool kit 527 would undoubtedly have had an impact on firewood procurement. A marked preference 528 for deadwood procurement optimally ensures the supply during short-term occupations 529 while green wood, which must be cut and dried over several months, is more suited to 530 long-term occupations. Combustion properties largely depend on the condition (dead or 531 living, dry or green) and morphological (size and diameter) state of wood more than 532 species (Allué et al., 2009; Henry and Thèry-Parisot, 2014; Thèry-Parisot et al., 2016; 533 2018; Vidal Matutano et al., 2017). Also, specific functions of the sites could influence 534 choices underlying the collection of wood, as is the case of Chauvet-Pont d'Arc, where 535 Scots pine type is selected to provide light and produce charcoal for use in rockart 536 motifs (Thery-Parisot and Thiebault, 2005, Thery-Parisot et al., 2018). 537

538 Our hypothesis is that the selection of Scots type pine wood in Mesolithic-Neolithic 539 transition Pyrenean sequences could be related to its capacity to produce a large amount of dead biomass, almost dry, easy to gather, and more or less regular in size and 540 diameter, resulting in a certain overrepresentation of this taxon in seasonal or temporary 541 settlements in rockshelters located in the low montane southern central Pyrenees (Figure 542 13). Apart from small calibre branches, probably related to the branch shedding of 543 544 defunct branches, the discrete presence of the largest diameter classes suggests the consumption of trunks as well (Figure 14). This does not necessarily imply that live 545 trees were felled for firewood use. Scots type pine forests tend to alternate live trees 546 with dead trees (Costa et al., 2001), so dry trunks that remain standing for years could 547 be easily cut down by prehistoric groups. Forest expansion attested from ca. 9.5 kyr cal 548 549 BP and changes in fire regimes (González-Sampériz, 2004; Gil-Romera et al., 2014) could have resulted in a higher biomass availability. 550

551 6. Conclusions and perspectives

552 Summing up, wood charcoal analysis at Esplugón reveals that Scots type pines (*Pinus* 553 *sylvestris* tp.) is the most consumed firewood along the entire archaeological sequence. 554 Although deciduous *Quercus* appears from the base of the sequence its use as fuel is 555 always secondary. These results match those from other studies in low montane 556 rockshelters containing long sequences of human occupation during the Mesolithic-557 Neolithic in the southern central Pyrenees.

558

The recurrent observation of anatomical wood decay features suggests the main use of deadwood as fuel. First dendro-anthracological results suggest the large use of branches and sometime trunks along the whole archaeological sequence. Small calibre branches are more abundant in the record, probably related to branch shedding of defunct branches. The discrete presence of the largest diameter classes points to the consumption of trunks, possibly taking advantage of the fact that *Pinus sylvestris* L. forests frequently alternate live and dry trees.

566

No important changes in forest management have been documented between the last hunther-gatherers and the first farmers at Esplugón, neither in terms of species nor of the exploited parts of plants. So, we propose that there was continuity in the patterns of firewood gathering as domestic fuel across the successive short-term occupations of the rockshelter mainly dedicated to the hunting of forest species despite the appearance of the first domesticated elements with the arrival of the Neolithic.

573

Finally, the application of dendro-anthracological tools to NE Iberia is novel. The development of this research line applied to Mesolithic-Neolithic transition and more recent archaeological contexts as well as to different taxa could be key for understanding different uses of wood, fuelwood procurement and forest management.

578

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598 Figure and table captions

599 <u>Figures</u>

Figure 1. Location of the Esplugón site (Huesca, Spain), the Station 1 sampled for
modern dendrological reference (Secorún) and the main surrounding archaeological
sites mentioned in the text. Base: MDT200 IGN (Spanish Government).

Figure 2. Location of the rock-shelter in relation with their current biogeographicalframework. Photographs: J.L. Peña and C. Mazo (University of Zaragoza).

Figure 3. West-east stratigraphic profile from the Esplugón site according to Laborda,2019.

Figure 4. Plotted dates 14C-AMS cal BP from the Esplugón site and GRIP climatecurve according to Obón et al., 2019.

Figure 5. Boxplot showing tree-ring width analysis results in the modern dendrological
reference dataset Secorún. PINI *Pinus nigra*, PISY *Pinus sylvestris*. (Rn) Total values
from branches, (T1) Values from 1.30 height trunks, (T2) Values from apical trunks,
(Tn) Total values from trunks.

Figure 6. Anthraco-typological key to sort *Pinus sylvestris* tp. archaeological charcoal
fragments into 4 anthraco-groups. Based in Dufraisse et al., 2017 for deciduous oaks.

615

616 Figure 7. Anthracological diagram from the Esplugón site (Huesca, NE Iberia).

Figure 8. Condition of wood at the charcoal assemblage from Esplugón by a binomial
system based on presence or absence. The percentages of alteration are calculated in
relation to the total number of studied fragments. (EM) Early Mesolithic, (LM) Late
Mesolithic, (EN) Early Nolithic.

Figure 9. Boxplots showing tree-ring width analysis results in the Esplugón site. Results
organized by chronological periods: (EM) Early Mesolithic, (LM) Late Mesolithic, (N)
Early Neolithic.

Figure 10. Boxplots showing tree-ring width analysis results in the Esplugón site.Results organized by diametre classes.

Figure 11. Evolution of the parts of plants exploited at the Esplugón site.

Figure 12. Architecture of *Pinus sylvestris* L. depending on whether it grew isolated(left) or in population (right) according to Riou-Nivert, 2001, 107.

Figure 13. Current vegetation around Esplugón. A. Map based on Forest Map of Spain
MFE50 MITECO, black star marks the site location. B. Deadwood accumulated in the
Guarga riverbanks because of the presence of large blocks of limestone. July of 2013.
C. *Pinus sylvestris* L. currently growing next to the site. Photographs: M. Alcolea.

Figure 14. Diagrams summarizing the results of the application of dendro-633 anthracological tools to wood charcoal fragments in the Esplugón site. At left, diametric 634 classes obtained by trigonometric method expressed in percentages by fragments and 635 636 corrected recomposed percentages by ADmodel (available in https://dendrac.mnhn.fr/spip.php?article237). At right, measured fragments grouped in 637 anthraco-groups based in anthraco-typological key showed in Figure 6. The results are 638 639 grouped in chronocultural periods.

640 <u>Tables</u>

Table 1. Radiocarbon dating from the Esplugón site in chronological order (OxCal v 4.3.2. IntCal13, Reimer et al., 2013; Bronk Ramsey, 2017). In italics, the dates which

are not in agreement with its stratigraphic position, interpreted as intrusions due to bioturbations.

- Table 2. Table summarizing applied dendrometric techniques according to Dufraisse etal., same volume.
- Table 3. Absolute and relative frequencies of the taxa identified in the Esplugón site.
 (EM) Early Mesolithic, (LM) Late Mesolithic, (EN) Early Neolithic.

Table 4. Anatomical alterations identified in the Esplugón charcoal assemblage by a
binomial system based on presence or absence. The percentages of alteration are
calculated in relation to the number of charcoal fragments identified as *Pinus sylvestris*tp. except in the case of vitrification, calculated in relation to the total number of studied
fragments. (EM) Early Mesolithic, (LM) Late Mesolithic, (EN) Early Nolithic.

Table 5. Diameter classes of charcoal fragments analysed by dendrometric techniques at
Esplugón site. AD% = % corrected recomposed. (EM) Early Mesolithic, (LM) Late
Mesolithic, (EN) Early Neolithic.

Table 6. Anthraco-groups to which charcoal fragments analysed at the Esplugón site
belong according Dufraisse et al., 2017. (1) Diameter <7 and growth rate <1 mm, (2)
diameter <7 and growth rate >1 mm, (3) diameter >7 and growth rate >1 mm, (4)
diameter >7 and growth rate >1 mm. (EM) Early Mesolithic, (LM) Late Mesolithic,
(EN) Early Neolithic.

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Sample	Lab. Ref.	Date BP	Date 2s cal BP	Archaeological	Phase
type				Layer	
Bone	Beta 338509	5970±30	6893-6731	3 sup	EN
Bone	Beta 283899	6120±40	7159-6903	4	EN
Bone	MAMS 30169	6166±23	7163-6997	6	EN
Bone	MAMS 30168	6282±22	7259-7170	3 sup	LM
Bone	Beta 313517	6730±40	7668-7514	3 inf	LM
Bone	MAMS 30166	6781±23	7670-7588	2	LM
Bone	Beta 306723	6950±50	7926-7681	3 inf	LM
Bone	MAMS 30167	7355±23	8291-8044	4	LM
Charcoal	GrA 59632	7620±40	8519-8366	4	LM
Charcoal	GrA 59634	7715±45	8585-8419	6	LM
Bone	Beta 306725	7860±40	8934-8547	5	EM
Charcoal	GrA 59633	8015±45	9021-8717	5	EM
Bone	Beta 306722	8380±40	9486-9300	6	EM

Dendro-anthracological parameter	Morpho-anatomical criteria	Dendro-anthracological tools
Growth rate	Tree-ring width	Dendrometry by image analysis software
Minimum diameter	Convergence of ligneous rays	Pith location tool and wood diameter estimation Analysis Diameter model (ADmodel)

Layer		6	4	5	4	4	3	inf	3 s	up	2	2
Chronology	E	Μ	E	Μ	L	Μ	L	Μ	E	N	E	N
Таха	n	%	n	%	n	%	n	%	n	%	n	%
Fraxinus sp.	-	-	-	-	1	0.5	-	-	-	-	4	1.7
Juniperus sp.	3	1.3	-	-	-	-	-	-	-	-	1	0.4
Pinus sylvestris tp.	222	93.7	193	92.7	194	99	216	96.9	220	90.5	183	76.6
Prunus sp.	2	0.8	-	-	1	0.5	-	-	-	-	2	0.8
Quercus sp. deciduous	4	1.7	13	5.7	-	-	6	2.7	23	9.5	44	18.4
Quercus coccifera/ilex	3	1.3	3	1.4	-	-	-	-	-	-	2	0.8
Rosaceae/Maloideae	3	1.3	-	-	-	-	1	0.4	-	-	3	1.3
Total determinable	237		208		196		223		243		239	
Undeterminable	7	2.9	28	11.9	54	21.6	27	10.8	7	2.8	11	4.4
Total	244		236		250		250		250		250	

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Layer	(6	4	5	4	4	3	inf	3 s	up	2	2
Chronology	E	Μ	E	Μ	L	Μ	L	M	E	N	E	N
Alterations	n	%	n	%	n	%	n	%	n	%	n	%
Cells collapse	117	52.7	81	41.9	79	40.7	104	48.1	129	58.6	64	34.9
Compession wood	111	50	83	59.7	135	69.6	146	67.6	88	40	46	25.2
Radial cracks	44	19.8	21	10.8	34	17.5	26	5.6	44	20	18	9.8
Total Pinus	222	100	193	100	194	100	216	100	220	100	183	100
Vitrification	14	5.7	28	11.9	61	24.4	31	12.4	8	3.2	14	5.6
Total fragments	244	100	236	100	250	100	250	100	250	100	250	100

Chronology	EM				LM			EN			
Diameter class	n	%	AD%	n	%	AD%	n	%	AD%		
0-2 cm	3	4.5	0	7	8.0	0	2	4.5	0		
2-4 cm	27	40.3	32.3	32	36.4	31.3	21	47.7	46.6		
4-7 cm	26	38.8	42.4	33	37.5	47.4	11	25	20.0		
7-10 cm	8	12.0	19.8	9	10.2	14.6	7	15.9	25.8		
10-14 cm	1	1.5	1.8	5	5.7	2.1	1	2.8	1.8		
14-20 cm	1	1.5	2.3	2	2.8	4.7	1	2.8	3.2		
>20 cm	1	1.5	1.4	0	0	0	1	2.8	2.7		
Total	67	100	100	88	100	100	44	100	100		

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Chronology	Ε	Μ	L	Μ	EN		
Anthraco-type	n	%	n	%	n	%	
1	53	79.1	62	70.5	31	70.5	
2	3	4.5	10	11.4	3	6.8	
3	8	11.9	16	18.2	10	22.7	
4	3	4.5	0	0	0	0	
Total	67	100	88	100	44	100	

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[0-2] [2-4] [4-7] [7-10] [10-14] [14-20] [20-4 Diametric classes











Referential samples

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charcoal-pith distance	tree-ring width	anthraco- groups	charcoal fragments
diameter < 7	narrow rings < 1 mm (slow growth)	1	
	large rings > 1 mm (fast growth)	2	
diameter < 7	narrow rings < 1 mm (slow growth)	3	
	large rings > 1 mm (fast growth)	4	
	1100	0	







Declaration of interests

 \boxtimes 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: