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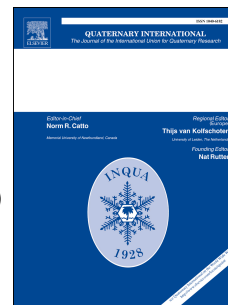
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1 **DENDRO-ANTHRACOLOGICAL TOOLS APPLIED TO SCOTS TYPE PINE**
2 **FORESTS EXPLOITATION AS FUEL DURING THE MESOLITHIC-**
3 **NEOLITHIC TRANSITION IN THE SOUTHERN CENTRAL PRE-PYRENEES**
4 **(SPAIN).**

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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**

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

38 1. INTRODUCTION

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

52

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

61

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

72

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

86

87 2. REGIONAL SETTING AND SITE DESCRIPTION

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

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

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

120 14 radiocarbon dates (Table 1 and Figure 4) place the occupation of the site (excluding
121 Stage 1) between 9.4 and 6.8 ka cal BP (Obón et al., 2019; Laborda, 2019). The Early
122 Mesolithic (EM) stage occurs during the last millennium of the Early Holocene (9.4-8.5
123 ka cal BP). The start of the Geometric Mesolithic or Late Mesolithic (LM) stage
124 coincides with the 8.4 and 8.2 arid events that give rise to the Middle Holocene in the
125 region (8.5-7.5 ka cal BP). Finally, the Early Neolithic (EN) stage occurs during the
126 Middle Holocene (7.3-6.8 ka cal BP).

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

136 sheltering and feeding nor storage structures have been found so far at the site (Laborda,
137 2019).

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

153

154 **3. Materials and methods**

155

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
162 excavated sediment through a 2-1 mm mesh. Also, flotation tests with a 0,5-0,25 mm
163 mesh of 20 litres of sediment per square meter and archaeological layer were performed
164 by M. Alcolea in the Laboratory of Prehistory of the University of Zaragoza in 2018.
165 No carpological remains have been found so far in the sampled archaeological deposit. .
166 Charred wood identified in this work corresponds to scattered charcoal in the sediment
167 from samples recovered by hand-picking, wet sieving and flotation. Scattered charcoal
168 is the result of consecutive combustion events reflecting successive collections of

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

172

173 3.2. *Methods.*

174

175 3.2.1. *Wood charcoal analyses.*

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

186

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

188 Charcoal taphonomy in anthracological research provide additional information about
189 plant growth, wood-gathering strategies and combustion and post-deposition processes
190 (Marguerie and Hunot, 2007; Théry-Parisot et al., 2010). In this study 4 relevant
191 features were recorded as absent or present: cell collapse, compression wood, radial
192 cracks and vitrification (Braadbaart and Poole, 2008; McParland et al., 2010; Moskal
193 del Hoyo et al., 2010; Thèry-Parisot and Henry, 2012; Henry and Théry-Parisot, 2014;
194 Vidal-Matutano et al., 2017; Caruso-Fermé and Thèry-Parisot, 2018; Allué and Mas,
195 2020; Courty et al., 2020). These features in archaeological charcoals provide relevant
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.*

201 Dendro-anthracological tools allow measuring dendro-anthracological parameters based
202 on morpho-anatomical criteria (Table 2). Dendro-anthracological techniques have been
203 applied on selected *Pinus sylvestris* tp. wood charcoal fragments with the aid of a
204 multizoom microscope (Nikon AZ100) that allows magnification factors from x4 to
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.
208 All measurements are taken in transverse (or cross) plane. The selection of fragments
209 was based on two criteria: size and preservation status. In terms of size, a minimum of 4
210 mm² is required in transverse (or cross) plane. Regarding the preservation status, the
211 microscopic wood anatomical features must not be deformed, particularly the ligneous
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.
215 Regarding microscopic wood anatomy features, the presence of visible ligneous rays
216 allow measuring the charcoal pith distance by applying the trigonometric method
217 (Dufraisse and García-Martínez, 2011; Paradis-Grenouillet et al., 2013). It is also
218 important that a modern reference dataset is available for measuring the caliber of pines
219 in the framework of the DENDRAC project (<http://dendrac.mnhn.fr/>) (Dufraisse et al.,
220 2020). The pith location tool is used to measure the distance between the charcoal
221 fragment and the theoretical location of the missing pith. This tool is based on
222 measurements of the angle and the distance between two ligneous rays and the
223 application of correction factors (Dufraisse and García-Martínez, 2011; Dufraisse et al.,
224 2020). The angle must be > 2 degrees and the distance > 2 mm for reducing the margin
225 of error and improving results in dendro-anthracological applications (Dufraisse et al.,
226 2017; 2020). The values were ordered into diameter classes chosen to be compatible
227 with the standards used in dendrometrical plans by foresters: 4 cm, 7 cm and 20 cm but
228 adding some wood cuts. For conifers diameter classes chosen are [0-2] cm, [2-4] cm, [4-
229 7] cm, [7-10] cm, [10-14] cm, [14-20] cm and >20 cm (Dufraisse et al., 2017).

230

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

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

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

242

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

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

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

266 3.2.4. *Anthraco-typological classification*

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

283

284 **4. Results**

285

286 *4.1. Taxonomic diversity.*

287

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

299

300 *4.2. Condition of wood.*

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

304 Cell collapse is commonly associated with decayed or rotten wood caused by fungi and
305 xylophagous insects (Moskal del Hoyo et al., 2010; Henry and Théry-Parisot, 2014;
306 Vidal-Matutano et al., 2017) or chemical and physical alterations that affect deadwood
307 (Allué and Mas, 2020). A high number of fragments shows signs of fungal degradation,
308 affecting 34.9-58.6% of pine charcoal fragments. This alteration inhibits the application
309 of dendro-anthracological techniques to fragments in which an important part of the
310 transverse surface is affected by this parameter.

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

317 The presence of radial cracks on the transverse plane affects 5.6-20% of pine charcoal
318 fragments. They are very common in charred wood because of the loss of volatile
319 compounds during the combustion process. Proposed as evidence of the use of green
320 wood as fuel, it has been demonstrated that the occurrence of radial cracks is not
321 correlated with moisture content (Théry-Parisot and Henry, 2012; Caruso-Fermé
322 and Théry-Parisot, 2018) being probably important other volatile compounds, e.g.
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.

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

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

334 4.3. *Minimum calibres of exploited stems.*

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

345 At the Esplugón site, the exploitation of small calibres predominates throughout the
346 entire archaeological sequence. Minimum diameter classes between 4 and 7 cm
347 predominate during the 2 Mesolithic stages (EM and LM). During the Early Neolithic
348 (EN) this diameter class diminishes while the diameter classes between 2 and 4 cm and
349 7 and 10 cm gain importance. Above 10 cm of diameter few fragments have been
350 documented (Table 5). Recomposed percentages (AD%) reinforce the observed
351 tendency.

352

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

360

361 4.4. *Growth rate.*

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

364 has been calculated to obtain growth rate of each charcoal fragment. Results show
365 calibrated values after applying correction factors (García-Martínez and Dufraisse,
366 2012).

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

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

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

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

389 **5. Firewood procurement in the southern central Pre-Pyrenees during the Early- 390 Middle Holocene**

391

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

393

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

395

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

408

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

415

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

417

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

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

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

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

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

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

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

470

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

481

482 5.2.2. Scots type pine forests exploitation as fuel.

483 The three native species of cryophilous montane pines growing in NE Iberia are
484 normally grouped in the taxon *Pinus sylvestris* tp. Montane Iberian pines include *Pinus*
485 *sylvestris* L., *Pinus mugo* subsp. *uncinata* (Ramond ex DC.) Domin, *Pinus nigra* subsp.
486 *salzmannii* (Dunal) Franco. Theoretically they grow nowadays at different altitudes in
487 NE Iberia: *Pinus nigra* between 500 and 800 masl, *Pinus sylvestris* between 800 and
488 1700 m a.s.l. and *Pinus uncinata* above 1800 masl (Costa et al., 2001), but usually they
489 overlap biogeographically and can interbreed (Quézel and Médail, 2003). These trees do
490 not show differences in wood anatomy allowing to identify each of them (Greguss,
491 1955; Schweingruber, 1990) so its past distribution at species level is not well-known
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 share
494 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
498 a monopodial structure composed of a single stem or trunk that reaches up to thirty
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).

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

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

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

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

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

566

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

573

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

578

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595

596

597

598 **Figure and table captions**

599 Figures

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

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

605 Figure 3. West-east stratigraphic profile from the Esplugón site according to Laborda,
606 2019.

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

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

613 Figure 6. Anthraco-typological key to sort *Pinus sylvestris* tp. archaeological charcoal
614 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).

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

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

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

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

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

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

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

640 Tables

641 Table 1. Radiocarbon dating from the Esplugón site in chronological order (OxCal v
 642 4.3.2, IntCal13, Reimer et al., 2013; Bronk Ramsey, 2017). In italics, the dates which
 643 are not in agreement with its stratigraphic position, interpreted as intrusions due to
 644 bioturbations.

645 Table 2. Table summarizing applied dendrometric techniques according to Dufraisse et
 646 al., same volume.

647 Table 3. Absolute and relative frequencies of the taxa identified in the Esplugón site.
 648 (EM) Early Mesolithic, (LM) Late Mesolithic, (EN) Early Neolithic.

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

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

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

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Journal Pre-proof

Sample type	Lab. Ref.	Date BP	Date 2s cal BP	Archaeological Layer	Phase
Bone	Beta 338509	5970±30	6893-6731	3 sup	EN
<i>Bone</i>	<i>Beta 283899</i>	<i>6120±40</i>	<i>7159-6903</i>	<i>4</i>	<i>EN</i>
<i>Bone</i>	<i>MAMS 30169</i>	<i>6166±23</i>	<i>7163-6997</i>	<i>6</i>	<i>EN</i>
Bone	MAMS 30168	6282±22	7259-7170	3 sup	LM
Bone	Beta 313517	6730±40	7668-7514	3 inf	LM
<i>Bone</i>	<i>MAMS 30166</i>	<i>6781±23</i>	<i>7670-7588</i>	<i>2</i>	<i>LM</i>
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
<i>Charcoal</i>	<i>GrA 59634</i>	<i>7715±45</i>	<i>8585-8419</i>	<i>6</i>	<i>LM</i>
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

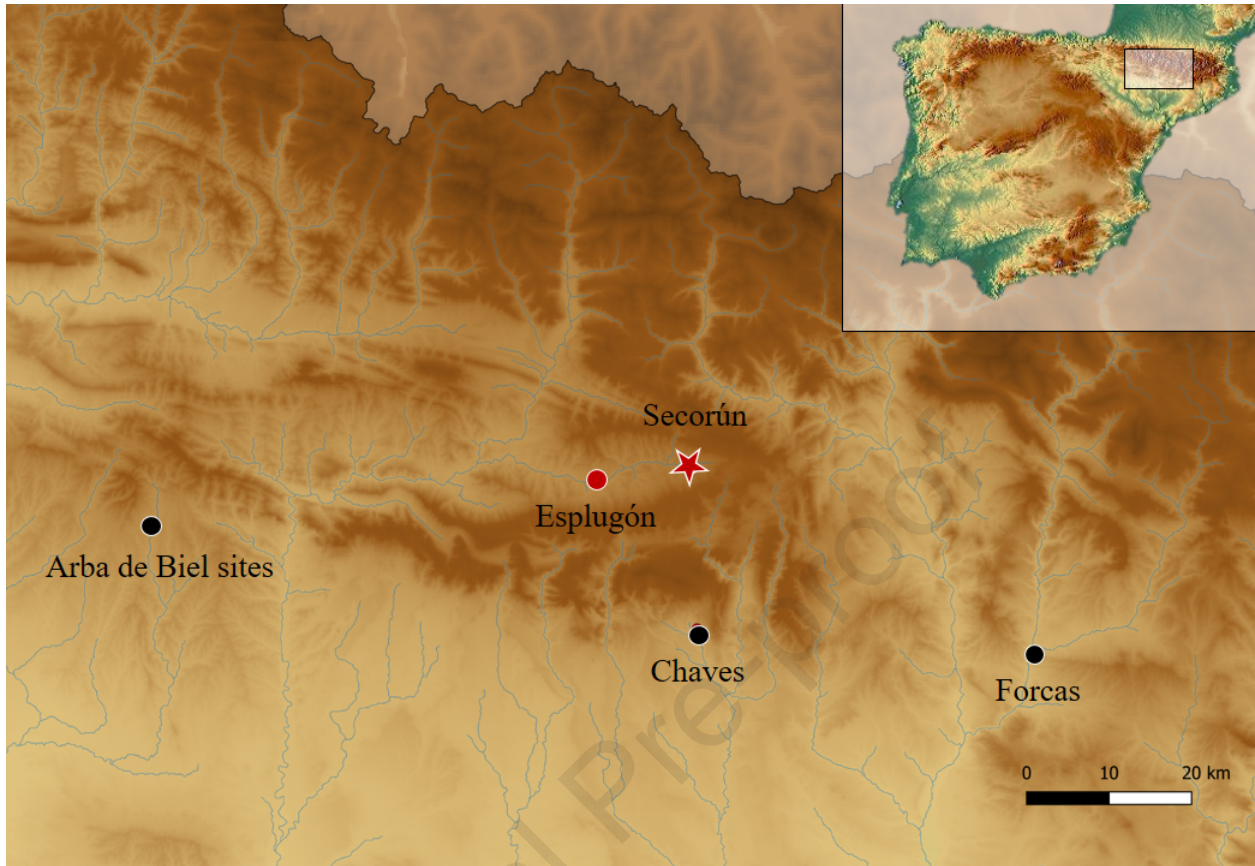
Dendro-anthracological parameter	Morpho-anatomical criteria	Dendro-anthracological tools
Growth rate	Tree-ring width	Dendrometry by image analysis software
Minimum diameter	Convergence of ligneous rays	Pith location tool and wood diameter estimation Analysis Diameter model (ADmodel)

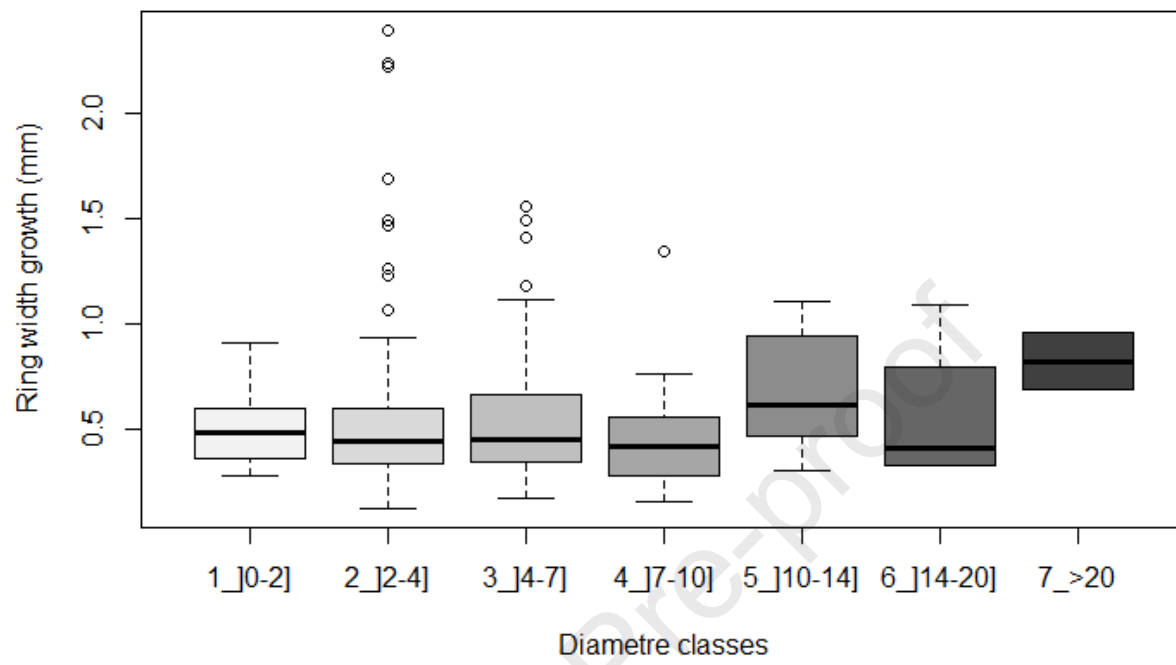
Layer	6		5		4		3 inf		3 sup		2	
Chronology	EM		EM		LM		LM		EN		EN	
Taxa	n	%	n	%	n	%	n	%	n	%	n	%
<i>Fraxinus</i> sp.	-	-	-	-	1	0.5	-	-	-	-	4	1.7
<i>Juniperus</i> sp.	3	1.3	-	-	-	-	-	-	-	-	1	0.4
<i>Pinus sylvestris</i> tp.	222	93.7	193	92.7	194	99	216	96.9	220	90.5	183	76.6
<i>Prunus</i> sp.	2	0.8	-	-	1	0.5	-	-	-	-	2	0.8
<i>Quercus</i> sp. deciduous	4	1.7	13	5.7	-	-	6	2.7	23	9.5	44	18.4
<i>Quercus coccifera/ilex</i>	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	

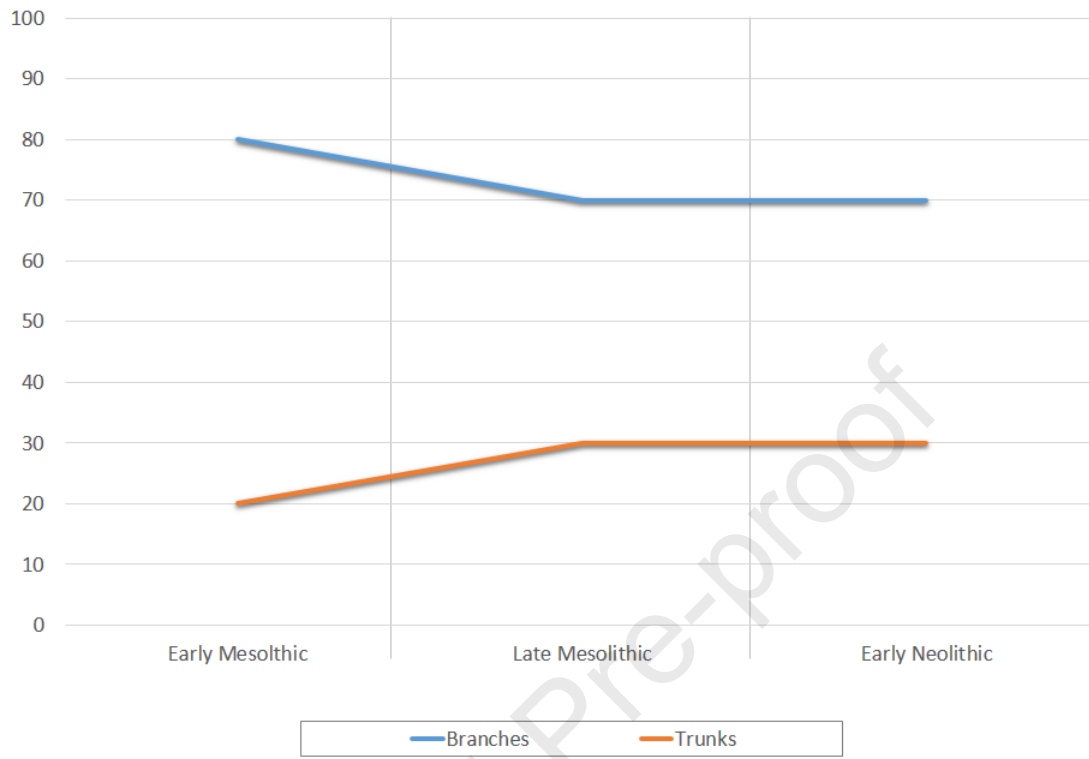
Layer	6		5		4		3 inf		3 sup		2	
Chronology	EM		EM		LM		LM		EN		EN	
Alterations	n	%	n	%	n	%	n	%	n	%	n	%
Cells collapse	117	52.7	81	41.9	79	40.7	104	48.1	129	58.6	64	34.9
Compression wood	111	50	83	59.7	135	69.6	146	67.6	88	40	46	25.2
Radial cracks	44	19.8	21	10.8	34	17.5	26	5.6	44	20	18	9.8
Total <i>Pinus</i>	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

Chronology	EM		LM		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



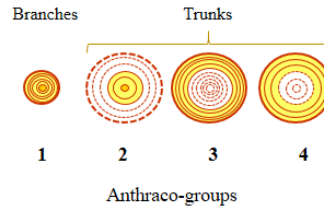
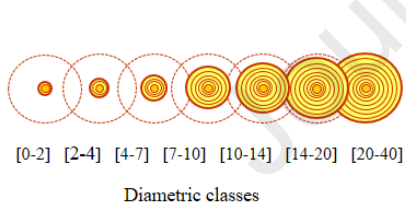
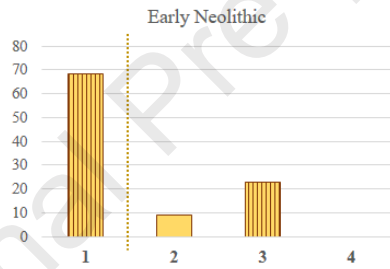
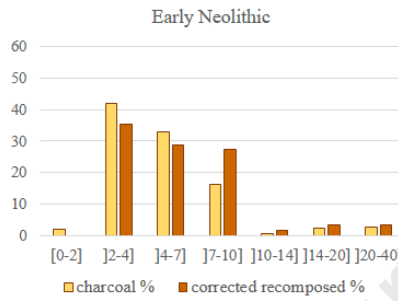
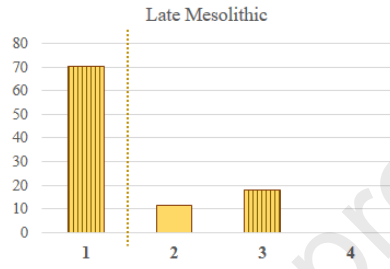
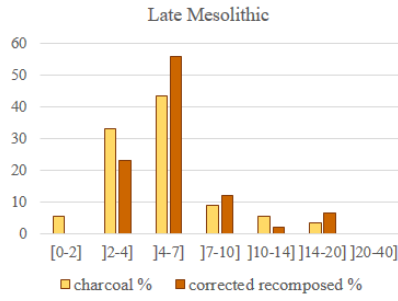
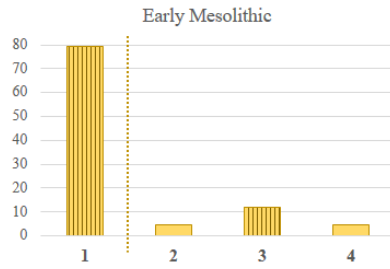
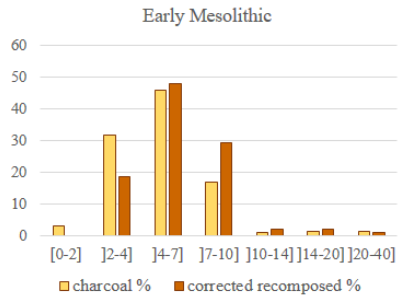




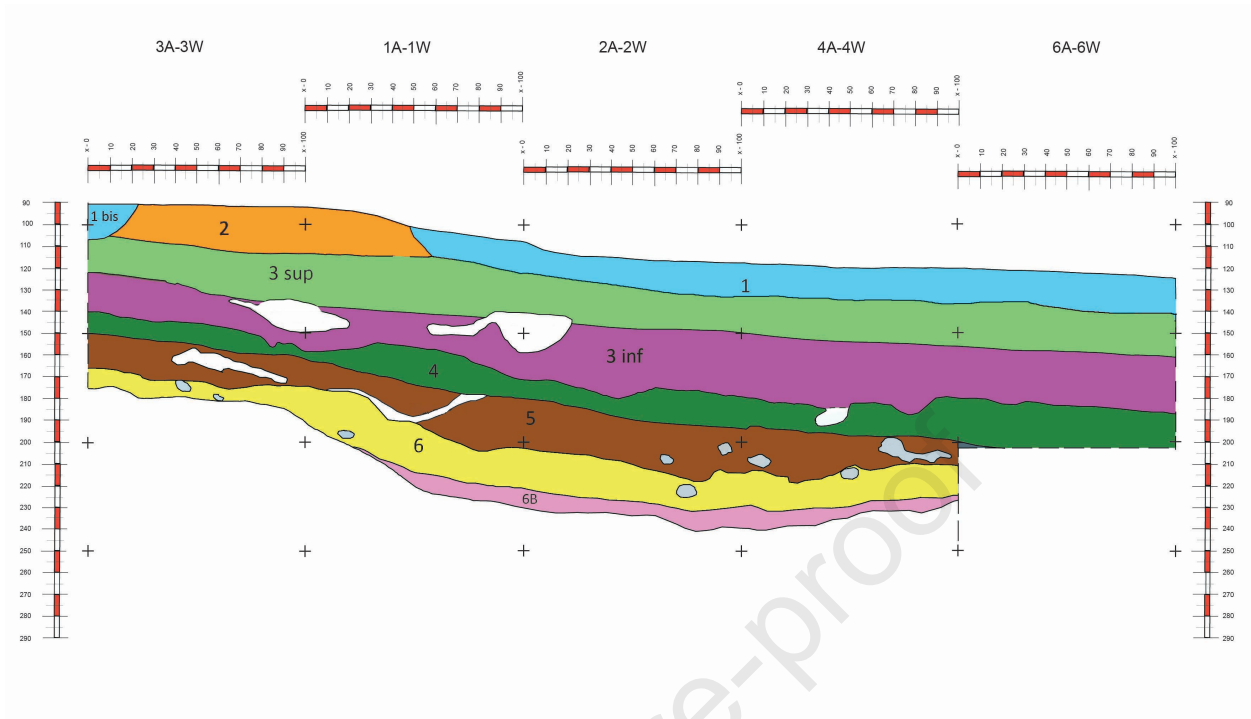


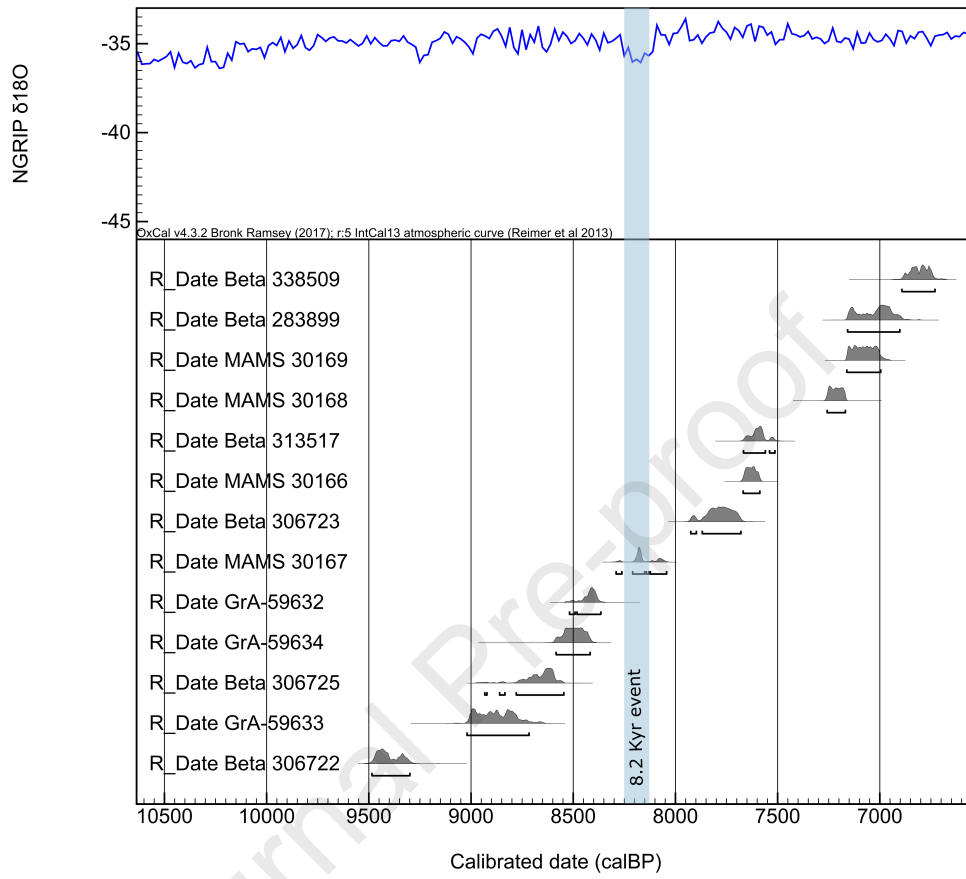
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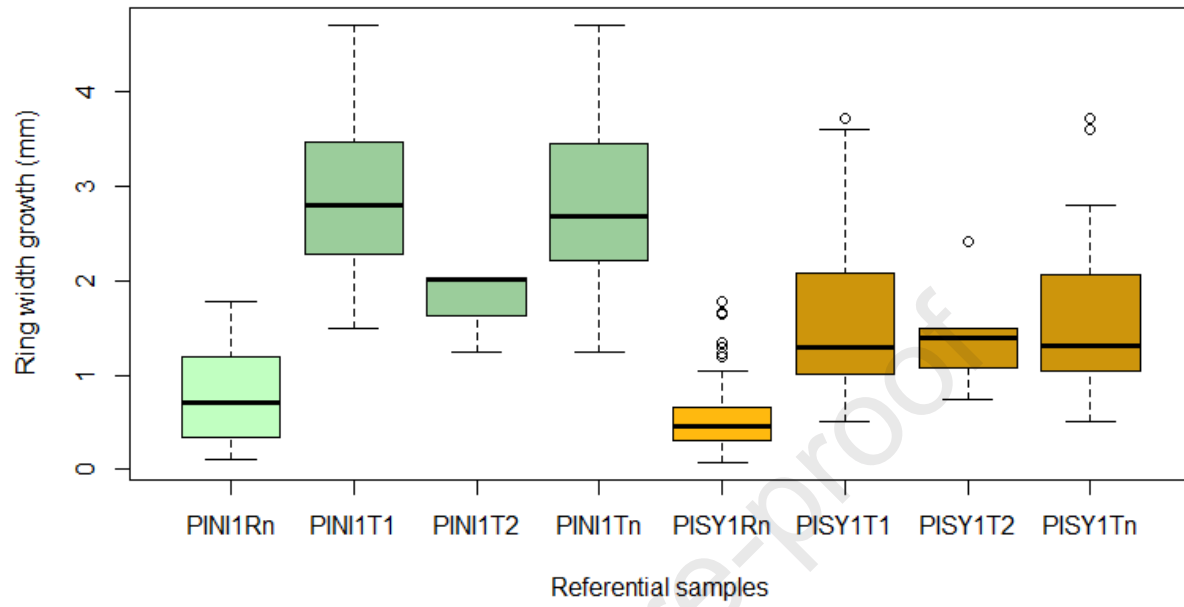





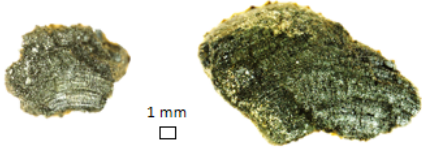

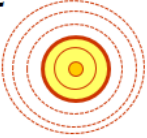







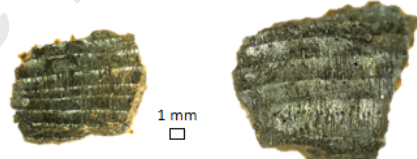


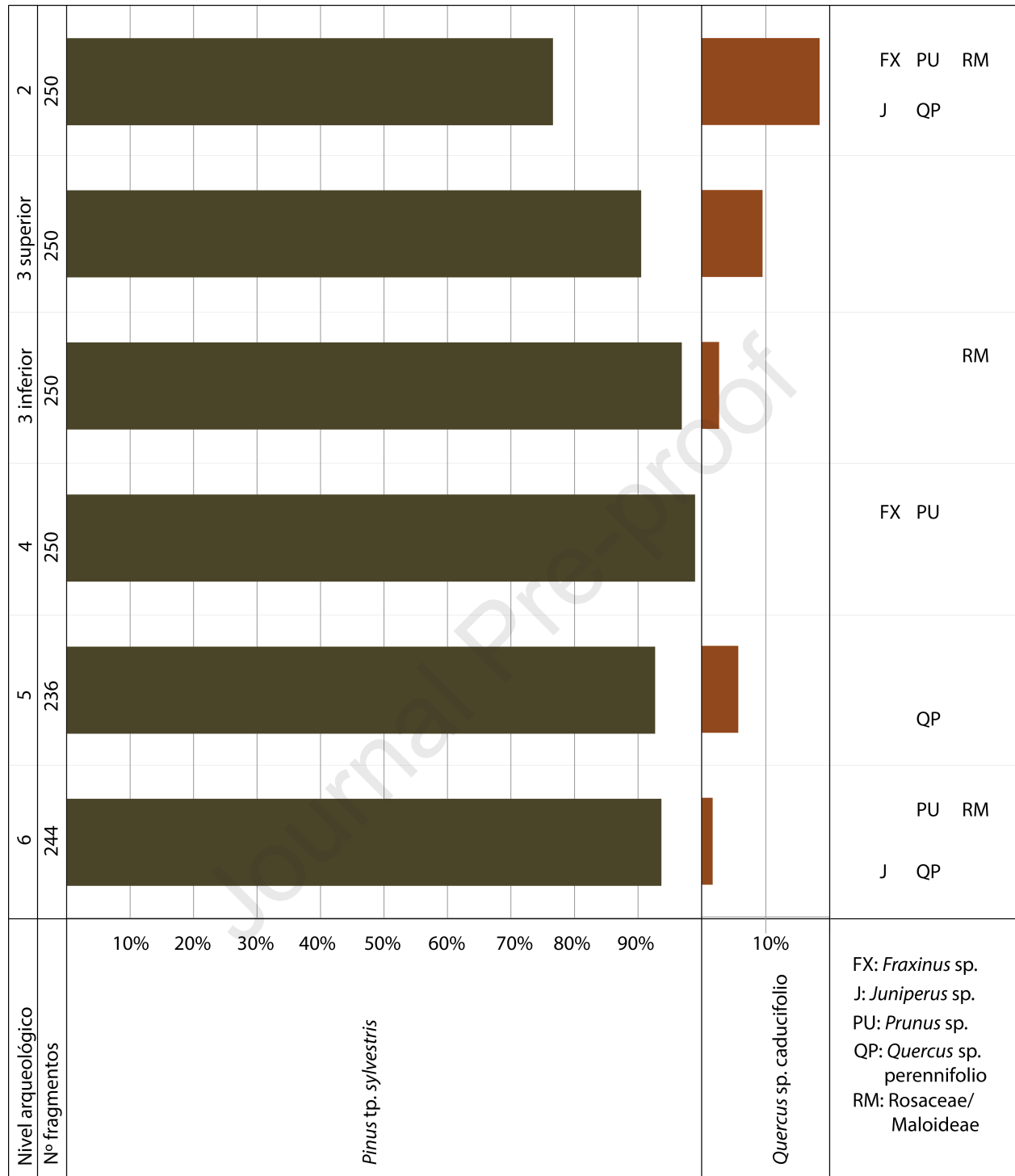


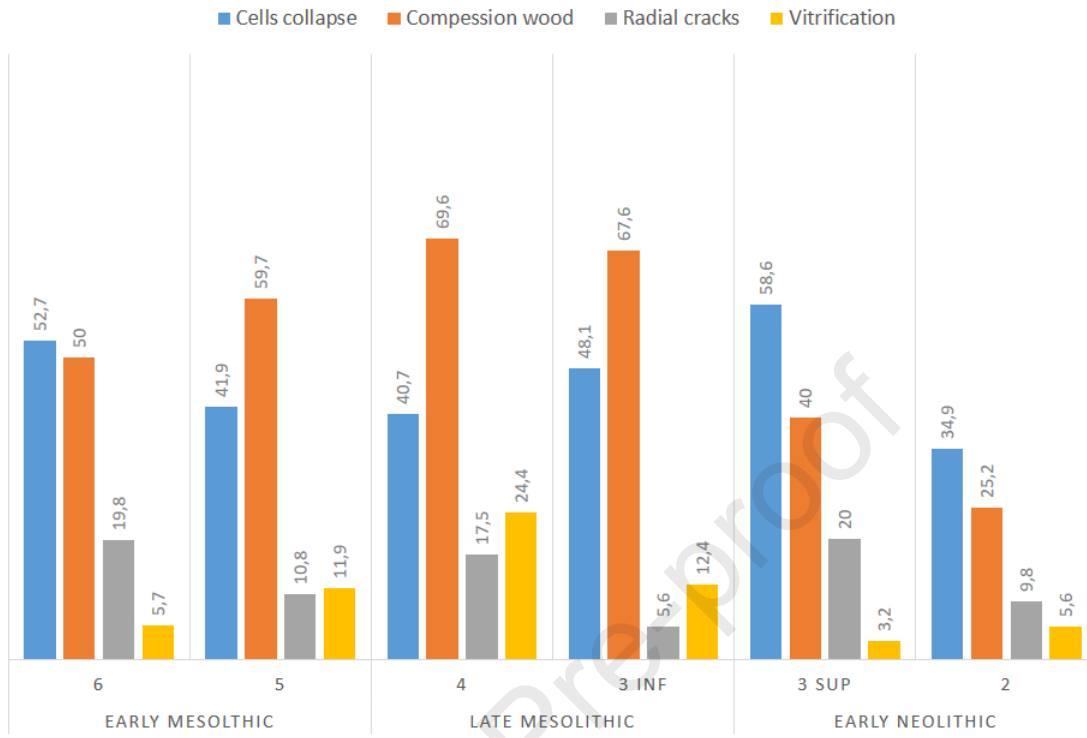


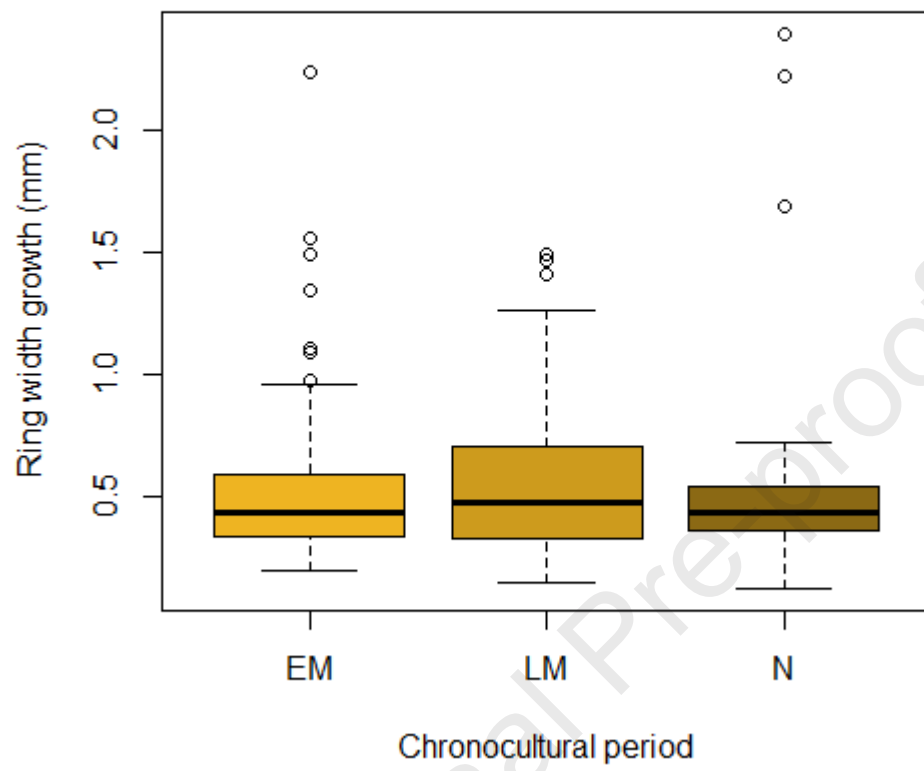




charcoal-pith distance	tree-ring width	anthracogroups	charcoal fragments
diameter < 7 	narrow rings < 1 mm  (slow growth)	1 	
	large rings > 1 mm  (fast growth)	2 	
diameter < 7 	narrow rings < 1 mm  (slow growth)	3 	
	large rings > 1 mm  (fast growth)	4 	







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:

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