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Dendrological reference dataset modelling with  
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1 **Anthraco-typology as a key approach to past firewood exploitation and woodland**  
2 **management reconstructions. Dendrological reference dataset modelling with dendro-**  
3 **anthracological tools**

4  
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17

18 **Abstract**

19 Charcoal analysis aims to study different aspects of forest management, techno-  
20 economical choices and their specific impact on past landscapes, as well as the impact of  
21 climatic events. However, at the present time, charcoal analysis is generally limited to the  
22 study of a list of taxa and their relative frequency, as the methods usually employed in  
23 dendrochronology to characterize past woodland, based on long tree-ring series, are not  
24 suitable for anthracological material. Today, the new challenge for charcoal analysis is thus  
25 to develop adapted dendrological tools. In this context, the aim of the ANR DENDRAC  
26 project "*Development of dendrometrical tools applied to anthracology: study of the*  
27 *interactions between Man, resources and environments*" was to characterize modern-day  
28 wood stands in accordance with historical woodland practices and convert dendroecological

29 data into parameters adapted to charcoal analysis. The purpose of this study is to define the  
30 dendrological features with the help of the anthracological tools without explaining the  
31 observed differences between the sampled stands (given the station variability, age and  
32 regeneration modes). The first step consisted in creating dendro-anthracological tools based  
33 on morpho-anatomical criteria that help to characterize growth, distinguish heartwood from  
34 sapwood and evaluate charcoal-pith distance. The second step involves characterizing three  
35 modern-day wood stands (coppice under standard, high forest and young stand formed by a  
36 mixture of seeded and coppice trees), defined by their structure, stand density and  
37 regeneration modes, using dendrological data measured on fresh wood material and  
38 modelled into anthracological data with the dendro-anthracological tools. In this way,  
39 anthracological types were defined for each wood stand, forming anthraco-typological  
40 models, which are useful for the interpretation of archaeological charcoal assemblages.  
41 Finally, an anthracological key is proposed to sort archaeological charcoal fragments in  
42 anthraco-groups before data processing.

43

44 **Keywords :** firewood management; dendro-anthracological tools; anthraco-typology;  
45 anthraco-group; deciduous oak

46

## 47 **1. Introduction**

### 48 1.1. Anthracology and past woodland reconstruction

49

50 The questions raised by relationships between people and the environment in time  
51 and space can be explored by archaeological, ethnographic or environmental approaches.  
52 The management of the environment for (plant or animal) food strategies reflects, to some  
53 extent, human societies and their organization, their lifestyles, their perception of the  
54 environment and the landscape in which they operate.

55 Forest exploitation in order to produce wood material for multiple needs, is perceptible  
56 at different scales: the tree, the woodland and the landscape (Michon, 2005, 2015); Humans

57 "domesticate" the tree by modifying its architecture, its growth cycle, its production and its  
58 reproductive functions. This domestication also concerns the forest ecosystem transformed  
59 by practices. Wood stands are shaped by and for societies living in them as a result of the  
60 installation of fields, herds and villages in forest areas. Variable spatial patterns results from  
61 this articulation between forest and agriculture, the landscapes.

62 Firewood management contributes to this "domestication". It is part of a complex  
63 system closely related to social organization, technical and economic systems, and the  
64 environment itself (Chabal, 1997; Picornell Gelabert, 2011; Dufraisse, 2012; Salavert and  
65 Dufraisse, 2014). Thus, archaeological charcoal fragments, residues of firewood selected  
66 and transported by humans, are valuable ecofacts reflecting use, techniques and woodland  
67 management, and are themselves conditioned by environmental resources (available wood  
68 resources, i.e. biodiversity and biomass).

69  
70 In forest science, the criteria characterizing wood stands are the composition  
71 (dominant and secondary species), stand density (number of stems per hectare), structure  
72 (distribution of age and diameter classes of trees) and modes of regeneration (seeded or  
73 vegetative renewal) (Rondeux, 1999). The methods usually employed in dendrochronology  
74 to extract this information are not suited to anthracological material. In dendrochronology,  
75 samples usually come from timber wood and generally from trunks and/or branches or roots,  
76 the wood is not charred, the methods are based on statistical tools that require at least 50  
77 consecutive rings and it is possible to individualize the signals (study of distinct elements). In  
78 anthracology, fragments derive from trunks and/or branches or roots, the wood is charred,  
79 fragmented and incomplete as it is partially reduced to ashes, the fragments present on  
80 average less than five rings and result from the exploitation of many indistinguishable  
81 individuals (Dufraisse, 2006; Marguerie, 2011). Consequently, in the absence of adequate  
82 tools, charcoal analysis is most often limited to the study of a list of taxa and their relative  
83 frequency without exploiting the information contained in the wood anatomy. The  
84 identification of the morphological characteristics of harvested firewood (part of the tree, age,

85 shape, etc.) still raises methodological problems even though it is a fundamental element for  
86 characterizing firewood exploitation techniques and reconstructing the populational and  
87 environmental parameters of wood stands.

88

89 In order to address this need to learn more about forest exploitation and practices, the  
90 ANR DENDRAC project “*Development of dendrometrical tools used in anthracology: study of*  
91 *the interactions between Man, resources and environments*” aims to convert  
92 dendroecological data measured on fresh wood material from modern-day oak wood stands -  
93 corresponding to different types of historical woodland practices - into parameters adapted to  
94 charcoal analysis, using a method similar to that developed by A. Billamboz, termed  
95 dendrotypology (Billamboz, 2011, 2014). His method consists in establishing a typological  
96 classification of tree-ring series according to their growth patterns. The application of a  
97 similar method in anthracology involves associating the identification of the taxa with the  
98 examination of dendrological and anatomical parameters; a concept that leads to the notion  
99 of dendro-anthracology (Marguerie et al., 2010). Deciduous European oak (*Quercus*  
100 *petraea/robur*) was chosen for its abundance in temperate forests, its anatomy with clearly  
101 identifiable growth rings and its representativity in anthracological spectra.

102 In the present study, we postulate that the characteristics of an assemblage of tree-  
103 rings can be exploited, without taking into account tree-ring series in terms of time series like  
104 in dendrochronology. The first step consisted in developing dendro-anthracological tools  
105 based on morpho-anatomical features. The second step was to convert dendroecological  
106 data to form an anthraco-typological grid, which could then be used as a key approach for  
107 the interpretation of archaeological charcoal assemblages. This approach was applied to  
108 three modern-day wood stands: a coppice under standard, a high forest and a young stand  
109 formed by a mixture of seeded and coppice trees. Analysis was conducted at different levels:  
110 the whole tree, and trunks and branches separately, in order to model different modes of  
111 wood exploitation.

112

## 113 1.2. The dendro-anthracological tools

114

115 Growth rate is a widely used dendro-anthracological parameter, but the successive  
116 tree-rings width series of each charcoal fragment must be localized as precisely as possible  
117 on the stem cross-section. In that aim, different dendro-anthracological tools are proposed in  
118 order i) to distinguish sapwood from heartwood which provides information about the minimal  
119 age of the wood (heartwood formation i.e. duraminisation starts when deciduous oak is  
120 around 25 years old) ii) to localize the tree-ring series in respect to the center of the stem, iii)  
121 to model dendroecological data from modern wood stands into dendro-anthracological  
122 parameters adapted to charcoal analysis.

123

### 124 1.2.1. The Heartwood-Sapwood discriminating tool

125

126 In some species the coloration of heartwood due to the deposition of lignins and  
127 polyphenols makes heartwood recognizable, but the charcoalification process that occurs  
128 during carbonization obliterates the colour difference, making this feature unusable in  
129 anthracology. Fortunately, in some *Angiospermae*, such as deciduous European oak  
130 (*Quercus petraea/robur*), the formation of tyloses (cellulose walls expansions) in earlywood  
131 vessels is an important feature of the changeover of sapwood to heartwood. However, tylosis  
132 formation also occurs in sapwood and increases with the formation of heartwood, from 0% of  
133 tyloses in the cambial region and close to 100% in the heartwood. Thus, we quantify the  
134 number of vessels sealed by tylosis in order to establish discriminating thresholds between  
135 sapwood and heartwood (Fig.1a) (Dufraisse et al., 2016). Trunks and branches of ten  
136 deciduous oak trees from 15 to 60 years old were sampled in three stations in order to  
137 evaluate the number of earlywood vessels with tylosis in sapwood and heartwood. For an  
138 application to archaeological charcoal (tyloses are preserved until 800°C), at least one tree  
139 ring and 15 vessels must be counted. The best strategy is to count 50 vessels spread over 3-  
140 4 tree rings. Thresholds of less than 65% for sapwood and up to 85% for heartwood are

141 significant. Besides the discrimination of sapwood and heartwood, the process of heartwood  
142 formation starts when deciduous oak is about 25 years old. The absence of heartwood is  
143 thus an indication of the exploitation of young wood (trunks or branches).

144

## 145 2.2. The pith estimation tool

146

147 The pith estimation tool is used to measure the distance between the charcoal  
148 fragment and the center of the stem (or the missing pith), named the “charcoal-pith distance”.  
149 This measurement is taken with the trigonometric pith estimation tool based on  
150 measurements of the angle and the distance between two ligneous rays (Fig.1b) (Dufraisse  
151 and Garcia Martinez, 2011; Paradis-Grenouillet et al., 2013). This tool was evaluated on  
152 fresh and carbonized oak wood discs with different angle values and distances between  
153 ligneous rays. This work enables us i) to propose exclusive criteria (angle  $< 2^\circ$  and distance  
154  $< 2$  mm) for reducing the margin of error and improving results in archaeological applications,  
155 ii) to establish correction factors linked to the trigonometric tool itself (underestimation of  
156 distance values between 5 and 10 cm) and the shrinkage which occurs during  
157 charcoalification, iii) to highlight that there are no reliable measurements for charcoal-pith  
158 distances beyond 12.5 cm, i.e. diameter of 25 cm (Dufraisse and Garcia Martinez, 2011;  
159 Garcia Martinez and Dufraisse, 2012).

160 The values were ordered into diameter classes chosen to be compatible with  
161 standards used in dendrometrical plans by foresters (Gaudin, 1996; Deleuze et al., 2014).  
162 For *Angiospermae* the conventional wood cuts are 4 cm, 7 cm, 20 cm, etc. Two cuts were  
163 added at 2 and 10 cm for more accurate interpretation of charcoal diameters, that is to say  
164 ]0-2] cm, ]2-4] cm, ]4-7] cm, ]7-10] cm, ]10-20] and >20 cm. For *Gymnospermae* it is more  
165 appropriate to add a cut at 14 cm, namely ]0-2] cm, ]2-4] cm, ]4-7] cm, ]7-10] cm, ]10-14] cm,  
166 ]14-20] cm and >20 cm.

167

### 168 2.3. The analysis diameter tool (ADmodel)

169

170 Burnt, wood undergoes both mass loss and charcoal fragmentation. Consequently,  
171 the distribution of the charcoal-pith distances does not indicate unburnt wood diameter.  
172 Therefore, an Analysis Diameter model (ADmodel) was developed, based on the fact that a  
173 trunk is biologically considered to be a stack of cones (Fig. 1c) (Dufraisse, 2002; 2006;  
174 Dufraisse and Garcia Martinez, 2011). These cones are hollow and their thickness  
175 corresponds to the amplitude of the diameter classes. It is based on a calculation table that  
176 provides the respective distribution of these cones in terms of volume. The ADmodel breaks  
177 down unburnt wood diameter into an expected distribution of charcoal-pith distances. In  
178 return, the ADmodel is a helpful tool to interpret the distribution of charcoal-pith distances  
179 from a charcoal assemblage as unburnt wood diameter (UWD). However, this model does  
180 not reconstruct the initially quantity of burnt wood (Théry-Parisot et al., 2011). In the present  
181 study, only the ADmodel running into UWD decomposition is used. In the present study,  
182 each cone thickness was also characterized by a growth rate (cumulated tree-ring width  
183 divided by the number of tree rings) and its sapwood/heartwood affiliation.

184

## 185 **2. Material and Method**

186

187 The general analytical protocol consists in sampling modern-day oak woodlands  
188 corresponding to specific archaeological questions, removing logs from felled trees, cutting  
189 wood discs from logs and producing experimental charcoal assemblages (Fig. 2). Various  
190 kinds of datasets were produced: i) dendrometrical plans to characterize tree morphology  
191 and wood stands (composition, structure stand density, regeneration modes), ii)  
192 dendrochronological data from wood discs, iii) anthracological data modelled with the  
193 dendro-anthracological tools.



194

## 195 2.1. Sampled stands

196

197 With respect to historical woodland practices and to answer to specific archaeological  
198 issues such as the distinction branch/ trunk or coppice /high forest three “contrasted”  
199 deciduous oak stands managed by the National Forestry Office (ONF) in France were  
200 chosen (Fig. 3). The first one is “ Les Cagouillères “, located in the Vienne department, on a  
201 limestone plateau (altitude: 115m). It is in an old abandoned coppice woodland, about 62  
202 years old, currently undergoing conversion to high forest. The second stand is “Bogny-sur-  
203 Meuse” located in the Ardennes department. This is a coppice-under-standard growing on an  
204 acidic brown soil on schists, about 68 years old. The third stand is “Le Bois de l’Or”, also  
205 located in the Ardennes department, near Bogny-sur-Meuse. This is a young stand, about 15  
206 years old, formed by a mixture of even aged seeded and coppice trees (altitude: 350m).

207

## 208 2.2. Stand analysis

209

210 In order to characterize the wood stands, forest inventory and dendrometric data were  
211 compiled. The basal area increment ( $m^2/ha$ ), stand density (number of stems per hectare),  
212 dominant height of the trees and the average square diameter were recorded distinguishing  
213 trees with diameters of more and less than 7.5 cm (table 1, Fig. 4).

214

## 215 2.3. Dendrometry and tree ring analysis

216

217 The dendrological information for each tree, such as diameter, age, growth rate and  
218 radial growth trend, was defined at breast height on the field and from disc located at 1.30 m  
219 above ground, as is usual in dendroecology. However, the nature and representativeness of  
220 archaeological samples are different in dendroecology and anthracology. Consequently, for

221 the conversion in anthracological data according to anthracological constraints, the  
222 dendrological data were measured in the whole tree.

223 For the study of tree ring-climate relations in sessile oak, six is the number of optimal  
224 trees to sample. For our purpose, and taking into account our archaeological questions, one  
225 to five trees were felled and registered meter by meter, one dominant tree in the coppice-  
226 under-standard at “Bogny-sur-Meuse”, four dominant stems from distinct multi-stem trees at  
227 “Les Cagouillères” and five coppice shoots and five seeded trees at “Le Bois de l’Or”.

228

229 For each tree, the total height, the height of the first large branch insertion on the  
230 stem and the height of the crown base were recorded as well as the diameter at breast  
231 height and regeneration modes. The set of tree morphology indicators is presented in table 1  
232 and figure 4.

233

234 In order to estimate the relative proportion of trunk and branches for each tree and  
235 each stand, each tree was cut into logs of 1-metre-long including branches with a diameter of  
236 more than 4 cm. A code was attributed to each log according to its position in the tree  
237 (height, number of branches, location in the branch). Length and circumference (at three  
238 points) of each log were measured to calculate the mean diameter and the volume. Branches  
239 with a diameter of less than 4 cm were packed into bundles according to two diameter  
240 classes; 0-2 cm and 2-4 cm. Each bundle was weighed. Sub-samples of wood were  
241 collected from each bundle to estimate the density of the wood and then to calculate the  
242 volume of each bundle.

243

244 In order to characterize each tree and then each wood stand at different levels (whole  
245 tree, and trunks and branches separately), one disc was removed from the extremity of each  
246 log. In the present study, a subsample of the set of discs was taken by selecting discs at  
247 different heights in the trunk and in the crown (23 discs for the four trees at “Les

248 Cagouillères”, 14 discs for the tree at “Bogny-sur-Meuse” and 77 discs for the 10 trees at “Le  
249 Bois de l’Or” (Table 2a, 2b).

250 The tree-ring widths (discriminating earlywood and latewood) of each disc were  
251 measured to the nearest 0.01 mm using a LINTAB measurement device and associated  
252 TSAP software (Frank Rinn, Heidelberg, Germany) along 5 radii and averaged in order to  
253 reduce intra-tree variability.

254 Each tree-ring was then associated with a diameter class (calculated by the  
255 cumulated ring widths) and sapwood/heartwood. Thus, the proportion of sapwood and  
256 heartwood was characterized by averaging tree-ring numbers, tree-ring width and wood  
257 volume.

258 The usual dendro-anthracological parameters were first independently considered to  
259 obtain a “whole tree” estimation, and then the trunks and branches were separated. i) the  
260 distribution of growth-ring width, ii) the proportion of sapwood/heartwood, iii) the distribution  
261 of the decomposed unburnt wood diameters (UWD) were recorded.

262

### 263 **3. Results**

264 3.1. Dendrological features of the three wood stands (Fig. 4).

265

266 For the four sampled 62 years-old trees from “Les Cagouillères”, the average  
267 diameter at breast height is 20.75 cm. The average tree height is 17.7 m and 90,4% of the  
268 wood volume is from to the trunk. The low proportion of branches, with a diameter of less  
269 than 7 cm, reflects an undeveloped crown (probably due to competition, a consequence of  
270 the abandonment of forest management). The dominant tree at “Bogny-sur-Meuse” is 68  
271 years old with a diameter of 33 cm at breast height. The height is 20.3 m with a first large  
272 branch at 7.7 m and a more developed crown; branches represent 37.4% of the tree volume  
273 and can reach a diameter of 20 cm. The trees at “Le Bois de l’Or” are 14 years old, their  
274 diameters average 10.21 cm, 8.6 m high, the trunk forms 78.38% of the volume and the  
275 diameter of branches less than 7 cm in diameter. Thus, the tree at “Bogny-sur-Meuse” is less

276 slender than trees at “Les Cagouillères” and “Le Bois de l’Or” (see the height/diameter ratio,  
277 table 1).

278 In the three sampled stands, trunk volume is always predominant and branches are  
279 poorly represented. The diameter 20-40 cm class is the best represented at “Bogny-sur-  
280 Meuse” whereas the 10-20 cm diameter class characterizes “Les Cagouillères”. The main  
281 volume at “Le Bois de l’Or” is distributed between 7-10 diameter but a few trees reach 11 cm  
282 and thus belong to the 10-20 cm diameter class.

283 Radial growth rate and growth trends are different in each stand. Tree-ring widths  
284 average 1.23 mm/year at “Les Cagouillères” coppice, and the growth trend has been  
285 decreasing over the past 20 years due to strong competition between shoots, intra-tree and  
286 between stools. At “Bogny-sur-Meuse”, growth-ring widths average 1.35 mm/year and the  
287 growth trend has been decreasing slightly over the past 20 years. At “Le Bois de l’Or”,  
288 growth-ring widths average 2.99 mm/year and are marked during the 1 to 10 first years by a  
289 steady increase in the coppice trees while seeded trees are characterized by narrowest rings  
290 than coppice from around the pith to 6-7 years, followed by an intensive growth period before  
291 a relatively sudden decrease (for more details, see Girardclos et al., 2016).

292

### 293 3.2. Simple dendro-anthracological parameters

#### 294 3.2.1. Growth rate

295

296 The distribution of the growth rates indicates differences at stand and tree levels (Fig.  
297 5a). First, the difference in growth rate observed in § 3.1 and only based on one disc  
298 localized at 1.30 m in the trunk, is conserved when the whole tree is taken into account, what  
299 is more realistic for anthracology. The growth rate at “Les Bois de l’Or” is the highest,  
300 followed by “Bogny-sur-Meuse” and “Les Cagouillères”. For a same stand, we also note a  
301 significant difference between trunks and branches, the latter being characterized by a lower  
302 rate. Moreover, considering the different parts of the trunk (base, top, upper part in the  
303 crown), we note that the annual ring-width in the top of the bole is wider than in the lower

304 part, and that the growth rate of the trunk localized in the crown is comparable with branches  
305 (Fig. 5b). However, this latter observation is less clear at “Le Bois de l’Or”.

306

### 307 3.2.2. Sapwood/heartwood

308

309 The trees at “Le bois de l’Or”, less than 15 years old, are characterized by the  
310 absence of heartwood, contrasting with “Bogny-sur-Meuse” and “Les Cagouillères” (Fig. 6).  
311 However, at “Les Cagouillères”, heartwood formation is not yet initiated in branches.  
312 Conversely, the trunk and branches of the dominant tree at « Bogny-sur-Meuse » are  
313 characterized by heartwood and sapwood. The relative proportion of sapwood in trunk is less  
314 important at “Bogny-sur-Meuse” than at “Les Cagouillères”. Likewise, the average number of  
315 sapwood tree-rings is less important at “Bogny-sur-Meuse”. Nevertheless the average  
316 sapwood ring width is higher at “Bogny-sur-Meuse” reflecting more vigorous growth.

317

### 318 3.2.3. Diameters

319

320 The unburnt wood diameters (UWD) were decomposed with the ADmodel, according  
321 to the relative volume of each hollow cone composing the logs (Fig. 1c, 7).

322 The raw dendrological data indicate that there is little overlap between the diameters  
323 of branches and trunks. In fact, the low proportion of the trunk represented in the smallest  
324 diameter classes corresponds to the upper part of the trunk localized in the crown. Therefore,  
325 for each wood stand, the distribution of the decomposed UWD of branches is clearly distinct  
326 from the trunk. Besides, as the volume of branches is weak, the wood diameter pattern for  
327 whole trees does not show clear differences with that of the trunk.

328

## 329 3.3. Combination of dendro-anthracological parameters

### 330 3.3.1. Decomposed UWD *versus* tree-ring width

331

332           The first combination consisted in assessing growth trends by characterizing each  
333 wood stand. In dendroecology, growth trends are obtained by combining tree-ring width and  
334 cambial age. Given that i) the analysis of tree-ring patterns in segment of cambial age is  
335 considered relevant for studying forest dynamics and development (Haneca et al., 2005) ii)  
336 the distance of the charcoal from the pith can be estimated by the charcoal-pith tool, we  
337 combined tree-ring width with diameter classes. For the dendrological data, average tree-ring  
338 width was calculated for each cambial age. For the modelled anthracological data, average  
339 tree-ring width was calculated for each diameter class (Fig. 8).

340

341           The radial growth trends of the three wood stands are different and the modelled  
342 anthracological data correspond well to their dendrological characteristics. Even though the  
343 anthracological data are smoother because of the calculation of average ring width per  
344 diameter class, the radial growth trend is consisting of i) a strong increase in the radial  
345 growth of trees at “Le Bois de l’Or”, reflecting a free juvenile growth, ii) the increase followed  
346 by a decrease at “Les Cagouillères” due to the high density of trees over a long period of  
347 time, iii) a slight decrease in the life of the tree at “Bogny-sur-Meuse” due to a managed  
348 coppice-under-standards. However, the differences observed between seeded and coppice  
349 trees at “Le Bois de l’Or” are no longer evident.

350           The branches at “Les Cagouillères” and “Bogny-sur-Meuse” are characterized by a  
351 lower growth rate than in the corresponding trunks (cf. § 3.2.1.) and by a downward growth.  
352 In contrast, the young seeded and coppice trunks at “Le Bois de l’Or”, with diameters  
353 comparable to the branches, are characterized by a clearly higher growth rate and a more  
354 upward growth.

355           The radial growth rate of whole trees is lower in the first diameter classes than in the  
356 trunk considered separately, as it includes the low growth rates of branches. Then, radial  
357 growth increases from the boundary of the step between diameters of trunks and branches.

358

359 3.3.2. Diameter classes *versus* heartwood/sapwood

360

361 The second combination aims to improve the interpretation of the distribution of the  
362 decomposed UWD by associating them with the presence or absence of heartwood, and the  
363 sapwood/heartwood ratio in each diameter class, as decomposed by the ADmodel (Fig. 9).

364

365 The distribution of heartwood/sapwood according to the diameter classes shows  
366 specific patterns for the different wood stands and possible exploitation modes (whole trees,  
367 trunks/branches separately).

368 At “Les Cagouillères”, where branches are characterized by the absence of  
369 heartwood, the volume of the trunk is mainly distributed in the penultimate diameter class.  
370 The pattern of the whole trees is similar to that of the trunk, as branches only represent  
371 9.58% of the volume. At “Bogny-sur-Meuse”, the same pattern is observable but the main  
372 volume is represented in the last two diameter classes. However, regarding the whole tree,  
373 sapwood is better represented in the small diameter classes than at “Les Cagouillères”, as  
374 branches account for 37.4% of the tree volume.

375 While the mature trees contain a central heartwood core (reflected by heartwood in  
376 the small diameter classes) and peripheral sapwood (reflected by sapwood in the largest  
377 diameter classes), the absence of heartwood in trunks from “Le Bois de l’Or” and in branches  
378 from “Les Cagouillères” is in agreement with young trunks and young branches respectively  
379 (less than 25 years old for oak). They are characterized by small diameters with sapwood,  
380 and the absence of heartwood and of large diameters. The biggest branches of the tree from  
381 “Bogny-sur-Meuse”, i.e. 10-20 cm, contain small amounts of heartwood, and traces of  
382 heartwood in the smaller classes.

383

384 3.3.3. Tree-ring width *versus* diameter classes *versus* sapwood/heartwood

385

386 The third combination consists in combining tree-ring width with the decomposed  
387 UWD and their respective affiliation to sapwood or heartwood (Fig. 10).

388 Globally, the pattern between whole trees and trunks from a same stand is similar.  
389 This is less obvious at “Bogny-sur-Meuse” where no disc from the upper part of the trunk  
390 without heartwood has yet been studied. However, we can expect the same pattern,  
391 characterized by sapwood and heartwood in all the diameter classes, and a lower average  
392 tree-ring width in sapwood corresponding to the external rings, which is coherent with the  
393 growth dynamic of trees (Fritts, 1976).

394 The exploitation of branches only is clearly distinct, with a low growth rate and the  
395 absence of heartwood in the case of young branches, as at “Les Cagouillères”. If branches  
396 are a little older as at “Bogny-sur-Meuse”, heartwood is absent in the largest classes of  
397 diameter. Lastly, the young vigorous seeded and coppice trees are characterized by a high  
398 growth rate in sapwood, while heartwood is absent.

399

#### 400 **4. Discussion and application to charcoal assemblages**

401

402 The dendrological characteristics of each wood stand, discriminating branches, trunks  
403 and whole trees, were defined with the help of the dendro-anthracological tools. The dendro-  
404 anthracological parameters (growth rate, heartwood/sapwood, diameters) were recorded  
405 independently of each other and then combined, forming anthraco-types (Fig. 11).

406

407 First of all, annual ring width was considered individually. Considering the whole tree  
408 and the trunk, ring width distribution is significantly different among stands. However, the  
409 distribution between seeded and coppice trees at “Le Bois de l’Or” is not significantly  
410 different. Likewise, the distribution between branches at “Les Cagouillères” and “Bogny-sur-  
411 Meuse” is not different. In each stand, branches are characterized by a lower growth rate  
412 than in the trunk. This observation is in agreement with the study of the variation of annual  
413 tree-ring width along the stem marked by a slight increase from the base to the top of the



414 trunk and a strong decreasing in the upper part of the trunk (in the crown). These results are  
415 similar to those of Dhôte et al. (1997), based on 82 *Quercus petraea* distributed in five  
416 regions in France. Consequently, growth conditions are mainly recorded in the trunk and  
417 branches should be avoided for palaeo-environmental reconstruction. This result fits with the  
418 method of D. Marguerie and J.-Y. Hunot (2007) whose the principle is to keep only tree-ring  
419 width measurements based on charcoal with large charcoal-pith distance.

420 At the scale of a charcoal assemblage, these data can be obtained by measuring  
421 each tree ring of each charcoal fragment and averaging them (per fragment). However, their  
422 interpretation remains problematic at this stage as they may come from different wood  
423 stands, trunks and/or branches, and it is not possible to distinguish them. In addition, it is  
424 difficult to interpret growth rate without contemporary, diachronic or modern-day reference  
425 standards.

426  
427 The presence or the absence of heartwood and the proportion of sapwood/heartwood  
428 are good indicators of the maturity of the wood. In anthracology, sapwood and heartwood  
429 can be distinguished using the proportion of vessels sealed by tylosis (Dufraisse et al.,  
430 2016). Then each fragment can be affiliated to sapwood or heartwood. However, if although  
431 the absence of heartwood reflects the exploitation of young trees, it is difficult to interpret  
432 sapwood and heartwood proportions as external and internal sapwood are not differentiated.

433  
434 Unburnt wood diameter (UWD) was decomposed using ADmodel. In a charcoal  
435 assemblage, charcoal diameters are obtained by measuring the charcoal-pith distance. The  
436 results indicate a diameter limit between branches and trunks for each wood stand, with  
437 almost no overlap, which is in agreement with the literature (Deleuze et al., 2014). However,  
438 the exploitation of whole trees is difficult to distinguish from the exploitation of trunks on  
439 account of the low branch volume. Consequently, if we hypothesize the exploitation of whole  
440 trees, the proportion of branches will be inconspicuous and difficult to distinguish from the  
441 exploitation of trunks. In addition, as regards the exploitation of different wood stands, it is

442 problematic to differentiate branches and young trunks solely on the basis of diameter  
443 distribution.

444

445 Thus, growth rate, heartwood/sapwood and wood diameters are three parameters  
446 that can be applied to charcoal assemblages. However, their use independently of each  
447 other is somewhat limited and sometimes difficult to interpret despite their information  
448 potential.

449 A first combination consisted in associating heartwood/sapwood and diameter  
450 parameters in order i) to differentiate the two kinds of sapwood: external sapwood in mature  
451 woods, and internal sapwood (absence of heartwood) in young woods ii) to improve the  
452 interpretation of the distribution of the decomposed UWD. Specific patterns were recorded  
453 according to wood stands and the exploitation modes (whole trees, trunks/branches  
454 separately). Young woods (trunk or branches) are characterized by absence of heartwood  
455 and small diameter classes, whereas mature wood is characterized by heartwood in small  
456 diameter classes and sapwood in the largest ones. In the scope of application to charcoal  
457 assemblages, this first combination yields four groups of charcoal fragments depending on  
458 their position in the wood: i) small diameter associated with sapwood corresponding to young  
459 woods, ii) small diameter associated with heartwood corresponding to the internal part of  
460 mature woods, iii) large diameter associated with heartwood corresponding to the middle part  
461 of mature woods and iv) large diameter associated with sapwood corresponding to the  
462 external part of mature woods.

463

464 The association of growth rates with the sapwood/heartwood ratio can provide  
465 information about the vigour of wood stands and tree morphology. For example, the  
466 proportion of sapwood is higher in trunks from “Les Cagouillères” (high forest) than in the  
467 trunk of the dominant tree at “Bogny-sur-Meuse” (coppice-under-standard). However,  
468 average sapwood ring-width and sapwood width are higher at “Bogny-sur-Meuse” than in  
469 “Les Cagouillères” (Fig. 7). This observation shows that i) for a same age (Bogny: 68 years

470 old, Cagouillères: 62 years old), the most vigorous trees have a more extensive sapwood  
471 surface (Lebourgeois, 1999) ii) sapwood width is higher in coppice-under-standard than in  
472 high forest (Dhôte et al., 1997). Thus, the under-representation of sapwood in the trunk of the  
473 tree in “Bogny-sur-Meuse” is probably due to a larger tree diameter, 33 cm as opposed to  
474 20.75 cm.

475

476 The third combination consists in associating tree-ring width and diameters  
477 (distribution of the decomposed unburnt wood diameters). For an application to charcoal  
478 assemblage, each tree ring is associated with a charcoal-pith distance, then to a diameter  
479 class and finally an average tree-ring width is calculated for each diameter class. Radial  
480 growth trends appear to be preserved keeping with dendrological radial growth. An original  
481 pattern marked by a low growth rate along the smallest diameter classes followed by a  
482 higher rate in the largest diameter classes may be a characteristic of the exploitation of  
483 whole trees. However, as it is often the case in dendroecology, one pattern may correspond  
484 to several scenarios. Here for example, a partial clearing of the wood stand could lead to a  
485 comparable growth trend. Thus interpretations have to be associated with the results  
486 established by other disciplines. In addition, an initial distinction between young trunks  
487 (coppice) and young branches becomes possible as their growth rate and growth trend differ  
488 (high rate and upward trend for coppice, low rate and downward trend for branches).  
489 However, no further distinction is visible between coppice and seeded trees at “Le Bois de  
490 l’Or”. In fact, only the proportion of earlywood is only significant when radius is up to 1,6 cm  
491 (Girardclos et al., 2016).

492

493 The last combination is the association of all the dendro-anthracological parameters:  
494 heartwood/sapwood, tree-ring width and diameters. Besides the distinction between young  
495 and mature woods based on the association between heartwood/sapwood and diameters, it  
496 becomes possible to discriminate branches from trunks among young woods. Indeed,  
497 branches are characterized by sapwood, a low growth rate and rather downward growth,

498 whereas young trunks (coppice and seeded trees) are characterized by sapwood, a high  
499 growth rate and rather upward growth.

500

501         Specific patterns appear depending on the stand and the potential types of wood  
502 exploitation (trunks and/or branches). Thus, anthracological types could be defined forming  
503 an interpretative grid which can act as a useful key for the interpretation of archaeological  
504 charcoal assemblages. Moreover, the recorded dendrological information is not the same  
505 depending on the position in the tree. For example, the information recorded in tree-ring  
506 width depends on the position of the charcoal fragment; tree-ring width and growth trend in  
507 young woods may be a good indicator of the origin of the wood in the tree (crown or bole)  
508 whereas stand characteristics (stand density according to strong or low competition between  
509 trees) are more perceptible in trunk, i.e. large diameter of mature wood (Marguerie and  
510 Hunot, 2007).

511         These results entail a new approach to anthracological material. Charcoal fragments  
512 have to be sorted according to their position in the stem cross-section and in the tree. For  
513 that purpose, an anthracological key based on dendro-anthracological parameters and  
514 forming anthraco-groups is proposed (Fig. 12).

515

516         Each oak fragment is characterized by a charcoal-pith distance, sapwood/heartwood  
517 affiliation and annual tree-ring width. The first division at the threshold of a diameter of 7 cm  
518 is often used by foresters and corresponds to the diameter limit between branches and  
519 trunks in deciduous oak forest. Concerning tree-ring width, charcoal fragments with regular  
520 and irregular tree-ring width series are taken into account separately. For example in  
521 northern France, according to V. Bernard (1998, p. 96), narrow rings are less than 0.7  
522 mm/year and large rings are between 0.7 and 3 mm/year for deciduous oak. Very large rings,  
523 up to 3 mm, can be also considered (i.e. 12 groups).

524         The use of this anthracological key enables us to sort charcoal fragments according  
525 to their position in the tree. Then, measurements of each batch can be processed separately.

526

527 To close, it is important to make several remarks concerning the dendro-  
528 anthracological tools and their applications.

529 i) The application of dendro-anthracological tools requires a minimum  
530 transversal plane size of about 4 mm x 4 mm and at least one whole growth-  
531 ring. The optimal number of fragments to analyze is around 100 per sampling  
532 unit (structure, layer, etc. according to the problematic).

533 ii) The choice of the diameter classes, chosen to be compatible with standards  
534 used in dendrometrical plans by foresters, seems to be relevant. However, a  
535 charcoal fragment can be classified in a class or the other when the value of  
536 the charcoal-pith distance is close to a limit but usually the interpretation is not  
537 affected.

538 iii) Given that it exists a boundary between the diameters of trunks and branches  
539 within a wood stand and that the part of the trunk located in the crown  
540 presents the same dendrological characteristics as a branch, it is more  
541 relevant and accurate for charcoal analysis to distinguish bole from crown  
542 than trunk from branch when considering oak and probably more generally  
543 *Angiospermea*. However, by *Gymnospermea*, the trunk can be easily followed  
544 until the apex with a clear separation of the branch material. Thus this  
545 distinction bole/crown or trunk/branch has to be adapted according to the  
546 architecture of the tree. In addition, variations in growth rates are often  
547 considered and interpreted in terms of environmental (light, soil or climate)  
548 and human factors (clearings or woodland management). However, we have  
549 to keep in mind that they can also result from a change in exploitation  
550 techniques (whole trees, trunks, branches). The use of the anthracological key  
551 may allow for the classification of the growth-ring width signal and thus bring  
552 more accurate information.

- 553 iv) Shrinkage during charcoalification leads to lower tree-ring width. This process  
554 is not consistent, depending on sapwood/heartwood and charcoal-pith  
555 distance. A preliminary study on shrinkage offers promising results in order to  
556 propose correction factors (Garcia Martinez and Dufraisse, 2012).
- 557 v) The relative frequency of the different taxa in charcoal assemblages is  
558 representative of the used biomass (wood volume). In the same way, the use  
559 of the dendro-anthracological parameters is based on the assumption that  
560 charcoal fragments represent the different parts of trees proportionally to their  
561 volume, with their dendrological characteristics (growth, ratio  
562 sapwood/heartwood, diameter). That is why the ADmodel is based on wood  
563 volume (and not on the number of fragments). However, we stress that, this  
564 model cannot reconstruct the quantity of initially burnt wood.
- 565 vi) As for the interpretation of tree-ring width (Marguerie, 1992, p. 72; Marguerie  
566 and Hunot, 2007), several conditions are required to interpret the dendro-  
567 anthracological parameters: charcoal assemblages must come from  
568 numerous trees, tree-ring series are randomly distributed in the transversal  
569 sections of charcoal fragments, ring series must be numerous enough and  
570 with a homogeneous width, acquisitions areas are subjected to the same  
571 climatic influences and the geological substratum must be homogeneous.

572

## 573 **5. Conclusion**

574

575 In line with the work of D. Marguerie (Marguerie, 1992, Marguerie and Hunot, 2007,  
576 Marguerie, 2011, Marguerie et al., 2010), combining charcoal identification and dendrological  
577 examination, the aim of this study was to improve methods to assess whether it was  
578 pertinent to develop quantitative measurements, such as estimating pith-charcoal distance,  
579 and whether the combination of dendro-anthracological parameters provides new information  
580 on wood exploitation and forest management.

581 Besides the measurement of tree-ring width, the present study is based on the  
582 development of three anthracological tools consisting in i) measuring charcoal-pith distance,  
583 ii) discriminating heartwood/sapwood and iii) modelling dendrological data to make them  
584 compatible with charcoal analysis. Three dendro-anthracological parameters i.e. growth ring  
585 width, charcoal-pith distances and heartwood/sapwood, modelled with ADmodel, were tested  
586 on modern-day oak wood stands chosen with respect to historical woodland practices: a  
587 coppice-under-standard, an old coppice undergoing conversion to high forest and a young  
588 stand formed by a mixture of seeded and coppice trees. For a more realistic representation  
589 of dendrological data according to anthracological constraints, different levels of analysis  
590 were considered: the whole tree, and trunks and branches separately, allowing us to further  
591 consider various modes of wood exploitation.

592 The dendro-anthracological parameters taken into account independently of each  
593 other provide interesting results but rather limited interpretation, especially for tree-ring width  
594 or sapwood/heartwood. Indeed the dendrological information cannot be interpreted in the  
595 same way depending on its position in the tree. For example, growth conditions and thus  
596 paleo-environmental information are essentially recorded in the trunk. In contrast, the  
597 combination of the dendro-anthracological parameters highlights specific patterns between  
598 organs, stands and regeneration modes, and enables us to establish an anthraco-typology  
599 forming an interpretative grid. A major result here is the identification of the position of the  
600 charcoal fragment belonging to young woods or internal/middle/external parts of mature  
601 woods and the distinction between branches and young trunks when associated with the  
602 tree-ring width. These results lead to the establishment of an anthracological key aiming to  
603 sort charcoal fragments into anthraco-groups according to their position in the tree and their  
604 growth rate.

605 Finally, these results offer new opportunities for the interpretation of archaeological  
606 charcoal assemblages as well as the development of new dendro-anthracological tools  
607 adapted to species other than deciduous oak.

608

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610

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614 helped to improve this publication.

615

616

617 **Captions**

618 Table 1 Dendrological characteristics of each wood stand and sampled trees.

619 Table 2a Analyzed wood discs and dendrological characteristics: Bogny-sur-Meuse; Les  
620 Cagouillères

621 Table 2b Analyzed wood discs and dendrological characteristics: Bois de l'Or.

622

623 Fig. 1. Dendro-anthracological tools.

624

625 Fig. 2. General analytical protocol developed in the ANR DENDRAC program. Experimental  
626 charcoal assemblages are not considered in this paper.

627

628 Fig. 3. Location of sampled stands.

629

630 Fig. 4. Main dendrological characteristics of the wood stands: modes of regeneration,  
631 average age, average diameter at breast height, relative proportion of trunks and branches  
632 (expressed according to volume), distribution of the diameters of trunks and branches (each  
633 log and its volume was attributed to an unburnt wood diameter class), average growth rate  
634 and growth trends (tree-ring width measurements were taken on each disc at a height of 1.30  
635 m, along 5 radii and averaged).

636



637 Fig. 5. Annual ring-width was averaged from 5 radii in each disc. (a) Distribution of annual  
638 ring-width (maximum and minimum values, 1st and 3rd quartiles and median) considering  
639 whole trees (white), trunks (brown) and branches (green). (b) Distribution of the annual ring-  
640 width along the trunks and in branches.

641

642 Fig. 6. Relative proportion of heartwood (brown) and sapwood (yellow) for each stand,  
643 considering whole trees, trunks and branches. The volume proportion of sapwood and  
644 heartwood was estimated for each disc, then each log and tree, and averaged for each wood  
645 stand. The average number of sapwood tree-rings, average sapwood width (cm) and  
646 average sapwood growth rate (mm/year) are indicated in boxes when heartwood is present.

647

648 Fig. 7. Diameter distribution (each log with its volume was attributed to a diameter class). At  
649 the top, the raw dendrological data (UWD = Unburnt Wood diameter) with trunks in brown  
650 and branches in green (branch = 100% and trunk = 100%). At the bottom, the decomposed  
651 UWD for the whole trees, trunks and branches for each stand.

652

653 Fig. 8. Dendrological data (simple line): average tree-ring width calculated by cambial age.  
654 Modelled anthracological data (solid line): average tree-ring width calculated for each  
655 diameter class.

656

657 Fig. 9 Cumulated curves of sapwood and heartwood proportions according to the  
658 decomposed UWD.

659

660 Fig. 10. Average tree-ring width according to the diameter classes (decomposed UWD) and  
661 their respective affiliation to sapwood (yellow) or heartwood (brown).

662

663 Fig. 11. Anthraco-typology for deciduous oak: an interpretative grid for archaeological  
664 charcoal assemblages.

665

666 Fig. 12. Anthracological key for deciduous oak to sort archaeological charcoal fragments into  
667 anthraco-groups. First, charcoal fragments are separated according to the charcoal-pith  
668 distances, more or less than 3.5 cm (i.e. diameter of 7 cm). Next, the charcoal fragment is  
669 attributed to heartwood or sapwood according to the proportion of vessels sealed by tylosis.  
670 Lastly, each fragment is characterized by annual tree-ring width.

671

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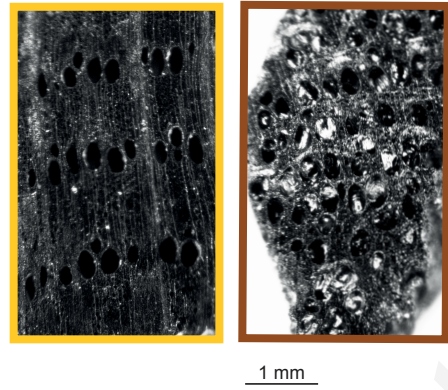
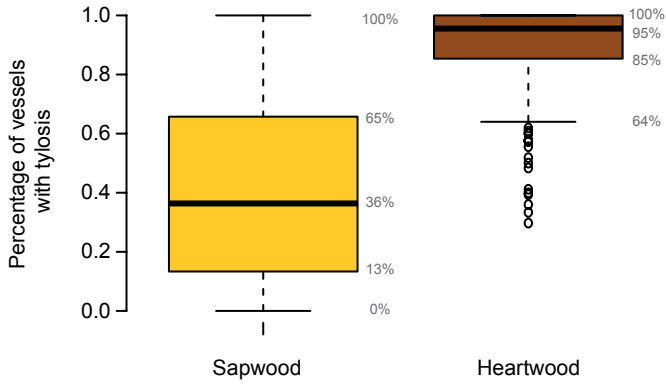
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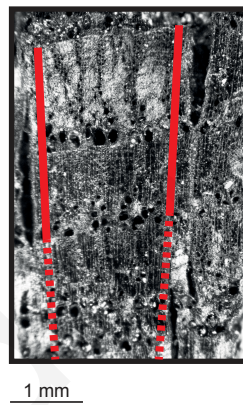
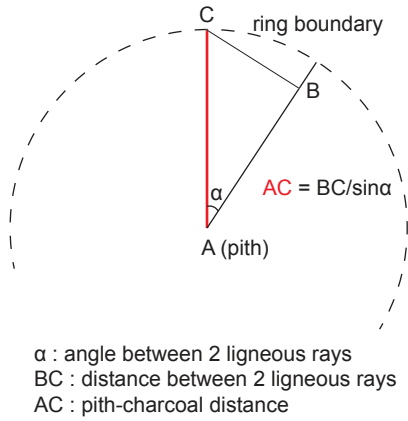
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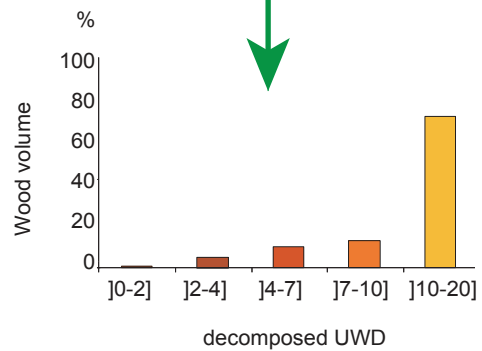
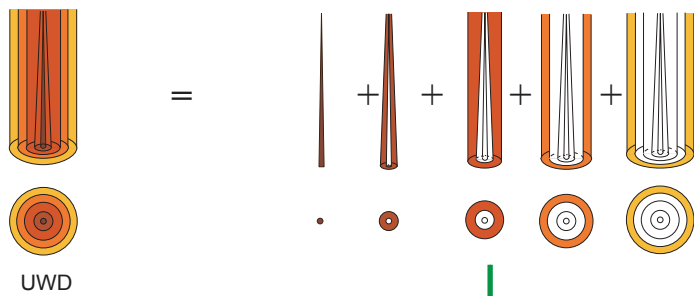
### a- Heartwood-Sapwood discriminating tool

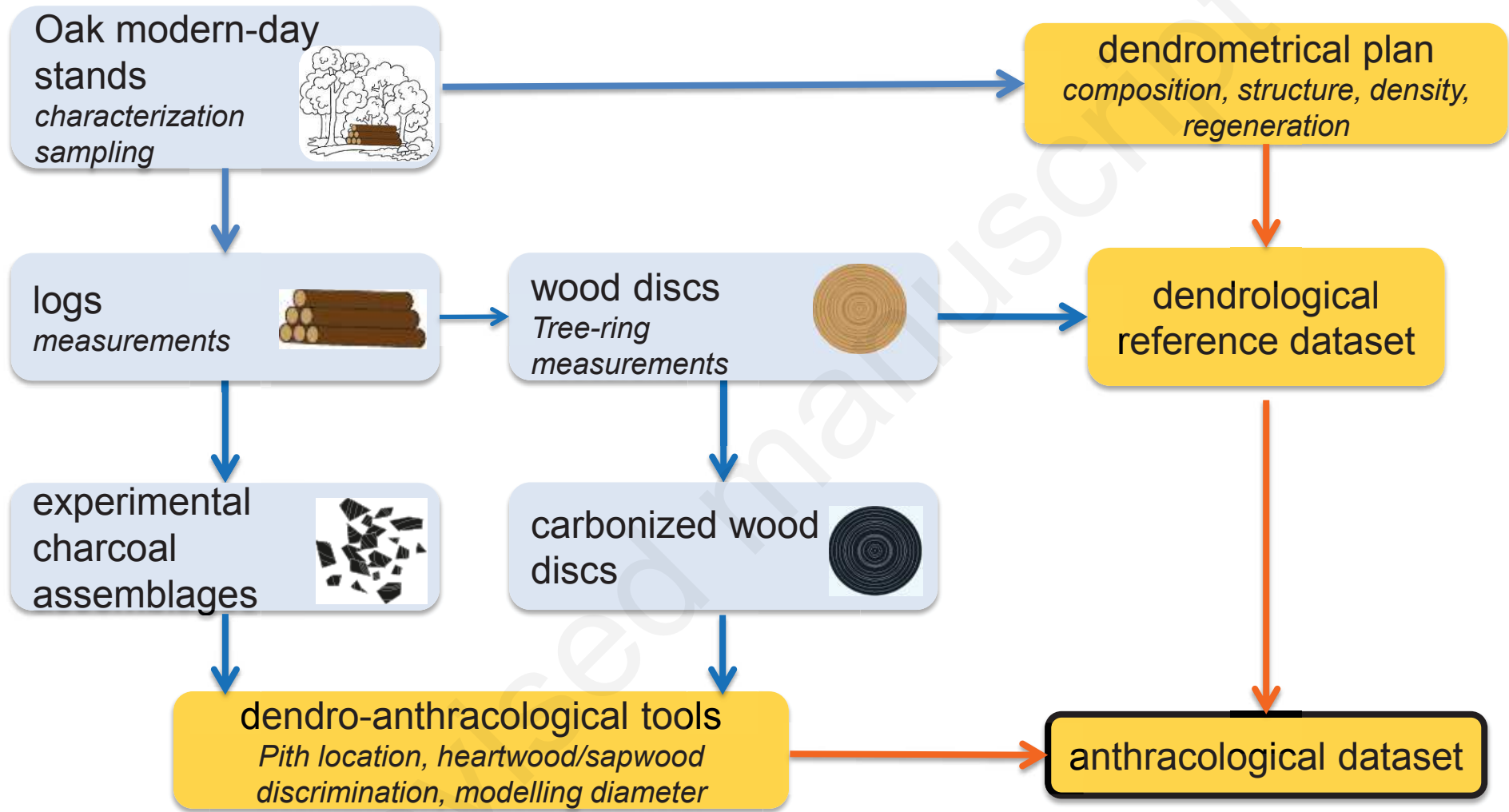


### b- Pith estimation tool

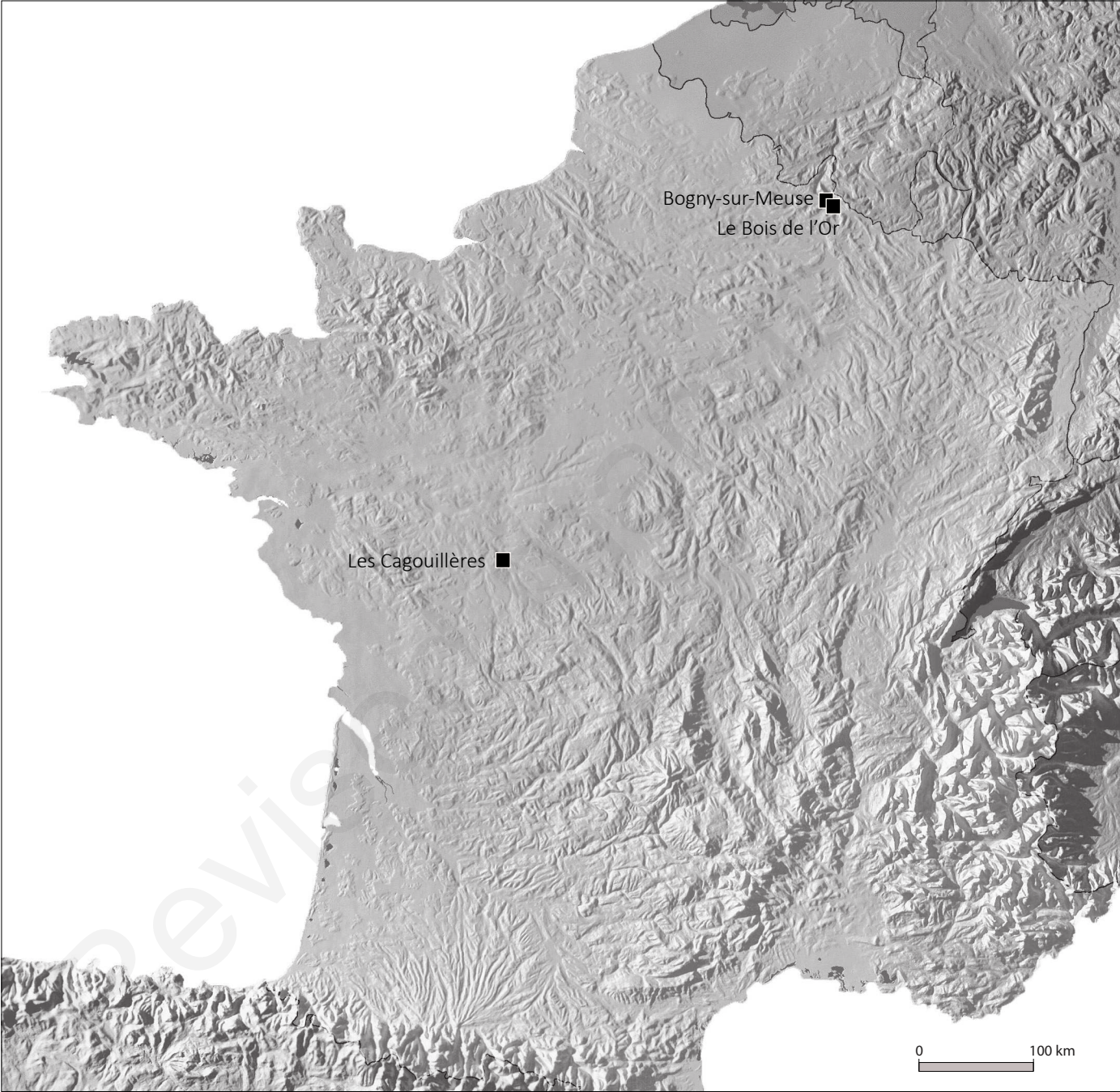


### c- Analysis Diameter tool









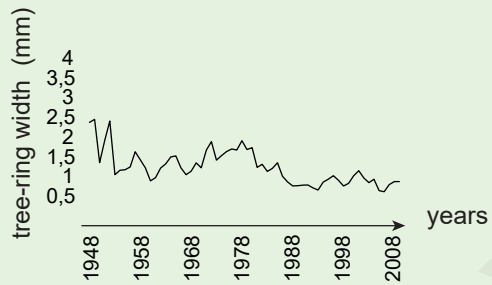
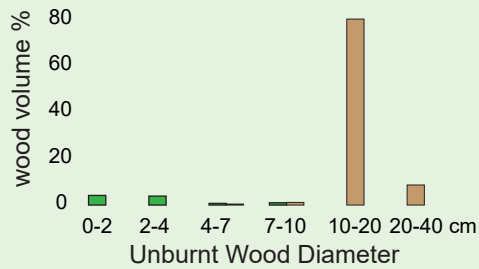
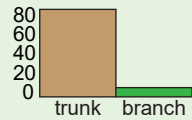
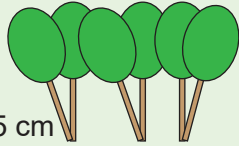
## Les Cagouillères

Abandoned old coppice  
4 trees

Average age = 62 yr

Average diameter = 20.75 cm

Average tree-ring width = 1.23 mm



## Bogny-sur-Meuse

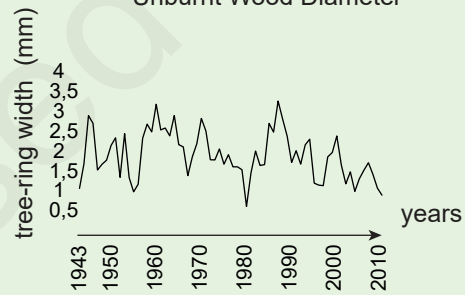
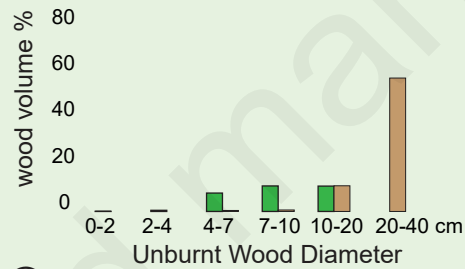
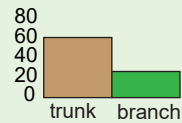
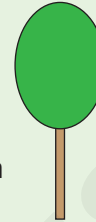
Dominant standard

1 tree

Age = 68 yr

Diameter = 33 cm

Average tree-ring width = 1.35 mm



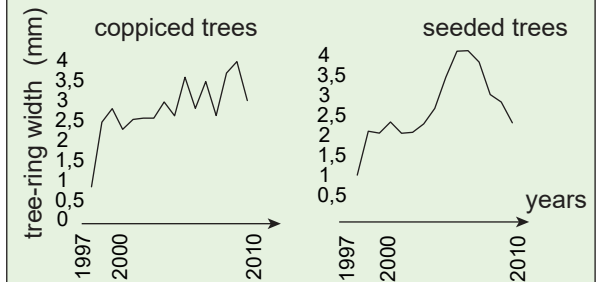
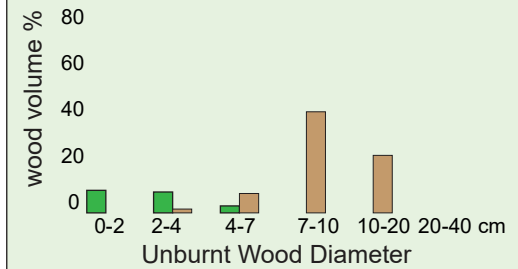
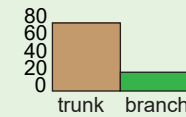
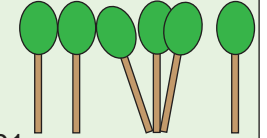
## Bois de l'Or

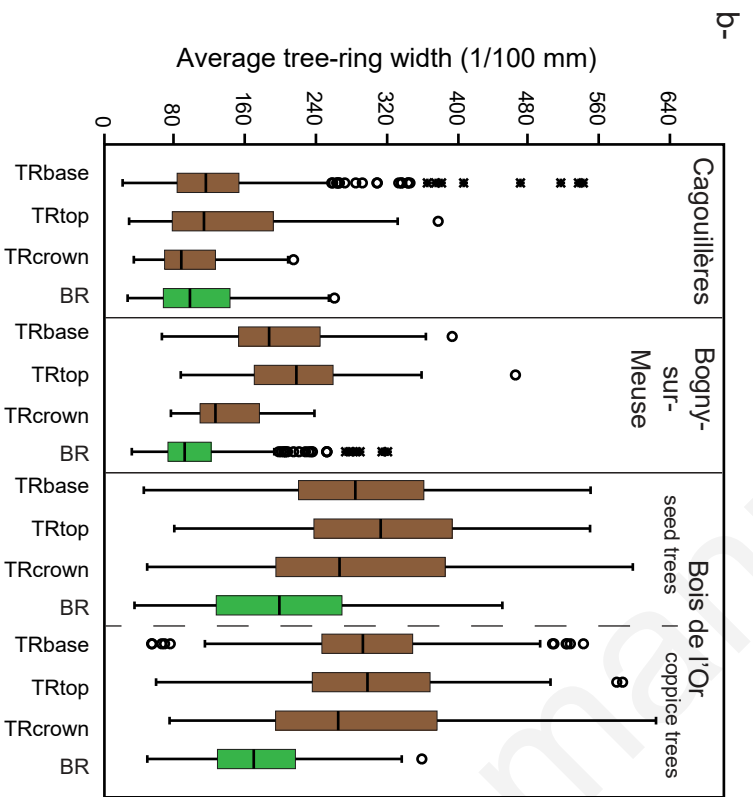
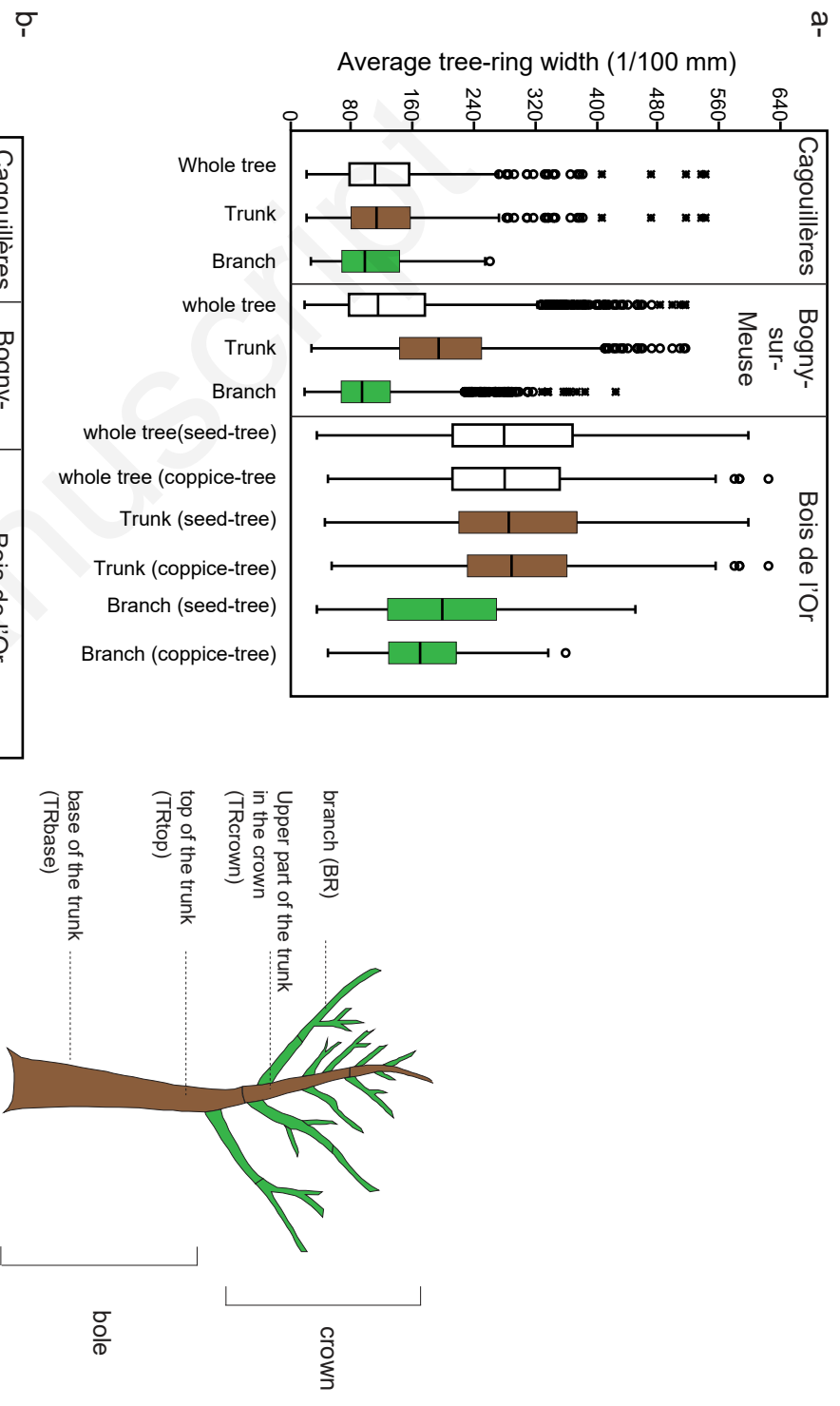
Mixture of seeded and  
coppiced trees

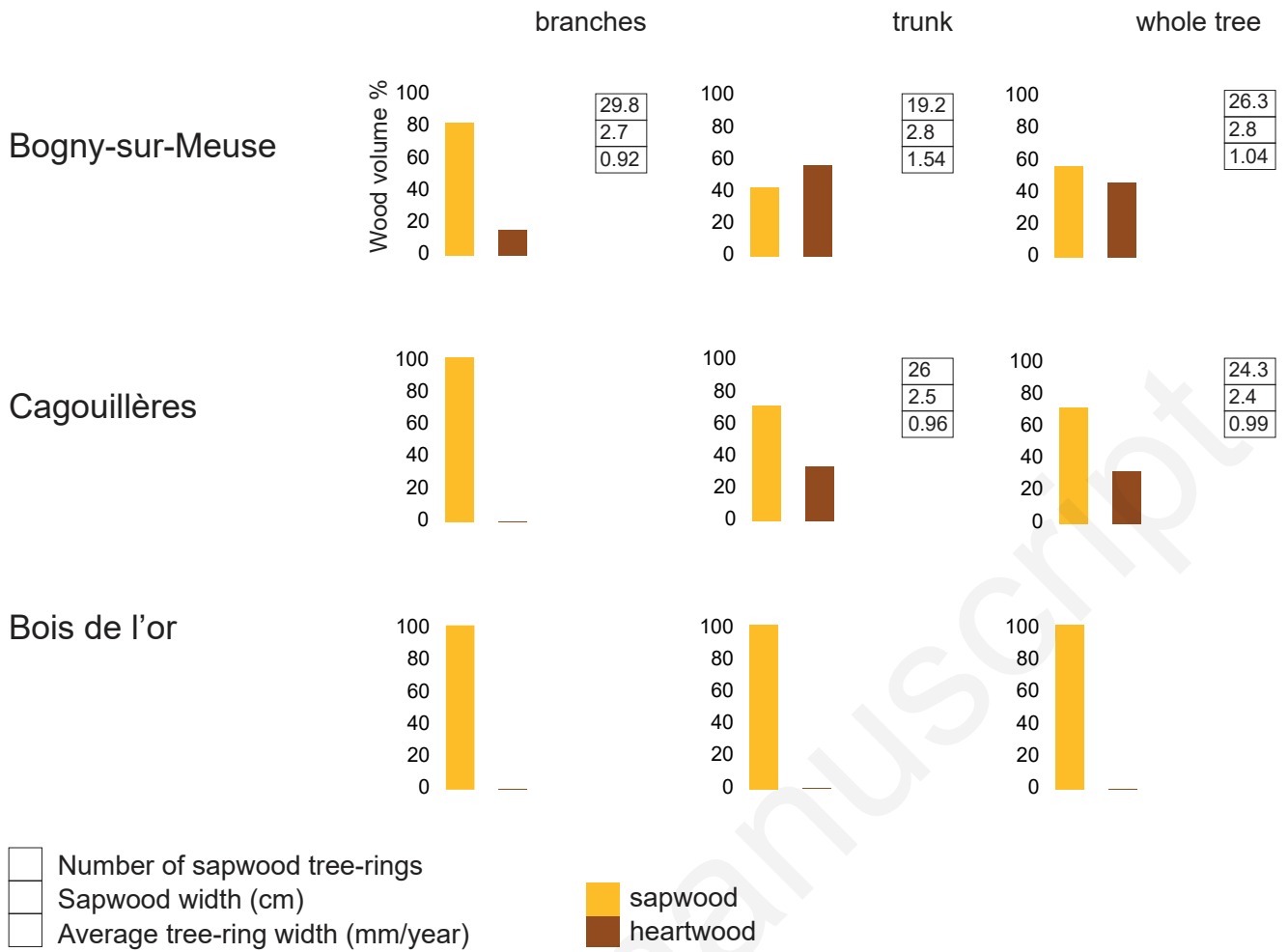
Average age = 14 yr

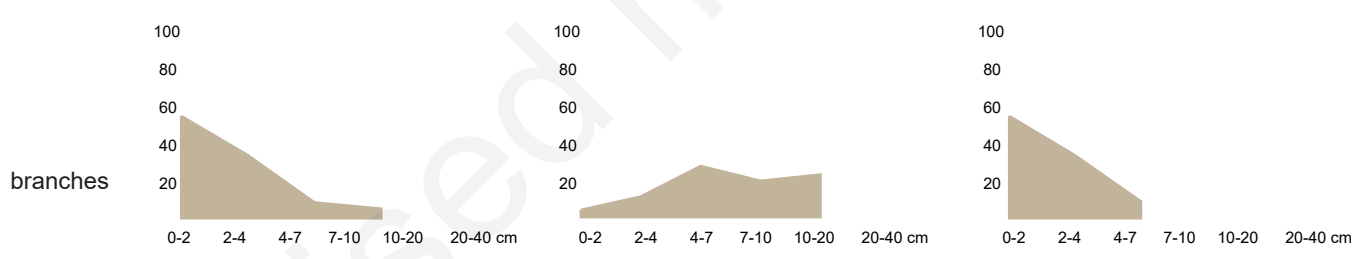
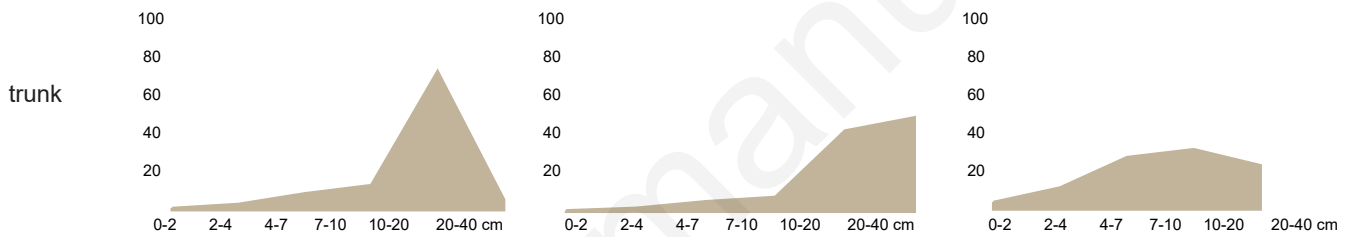
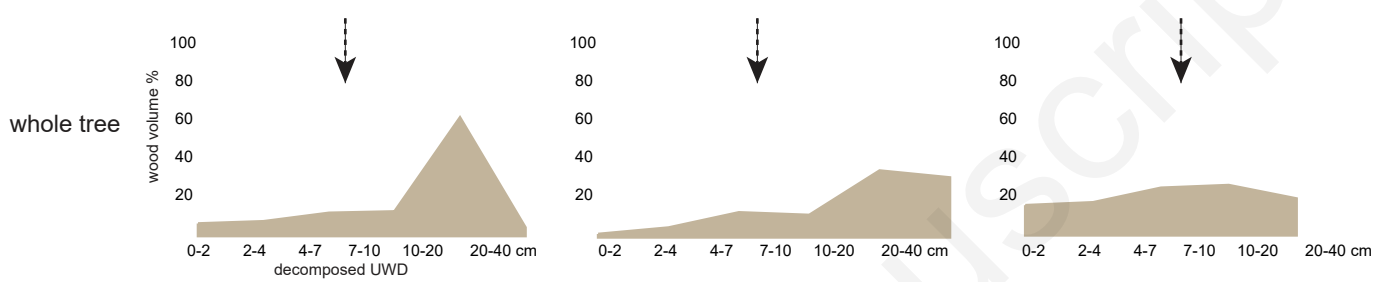
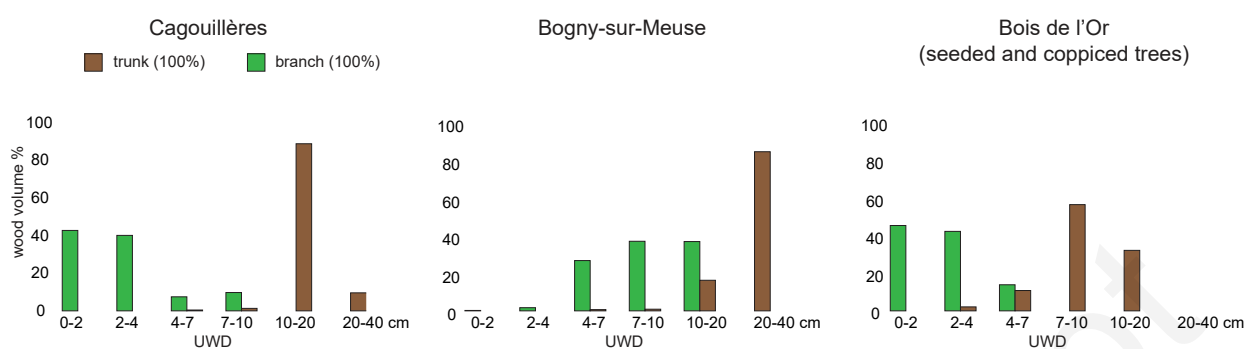
Average diameter = 10.21 cm

Average tree-ring width = 2.99 mm



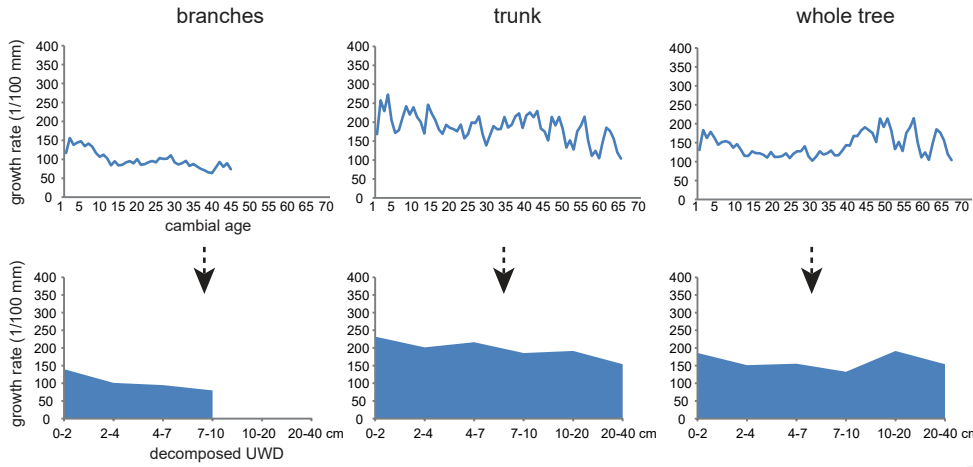




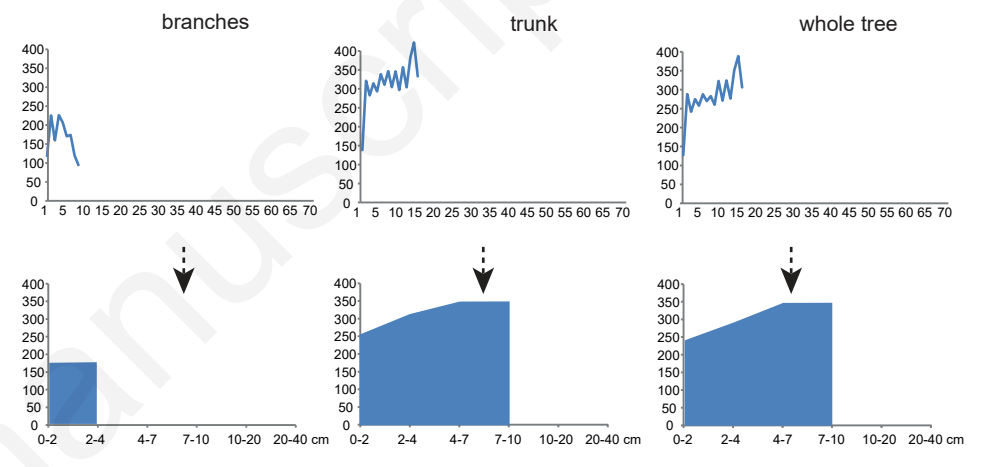


Revised manuscript

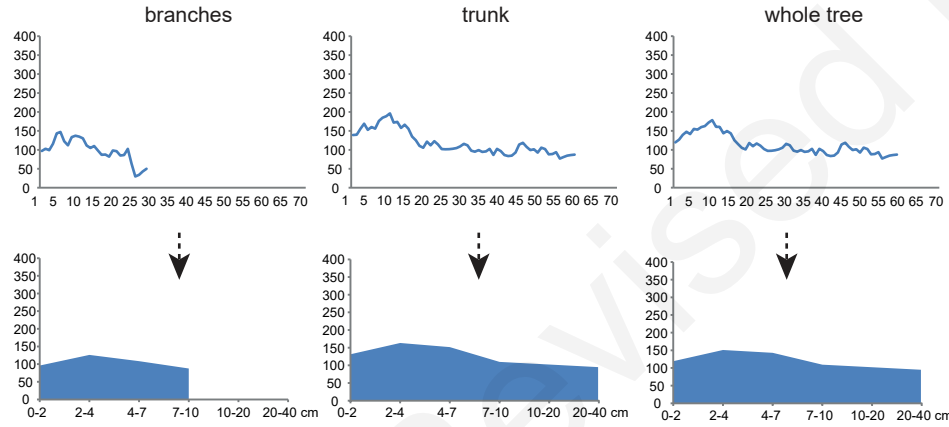
### Bogny-sur-Meuse



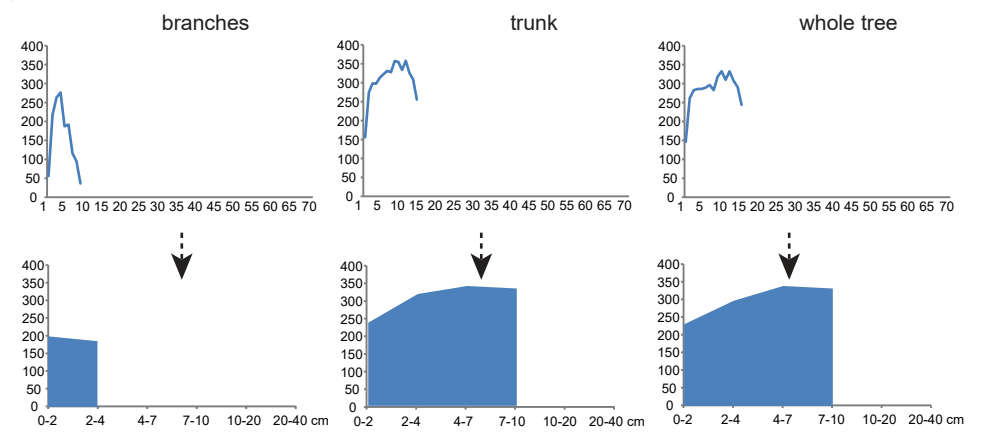
### Bois de l'or - coppiced trees



### Cagouillères



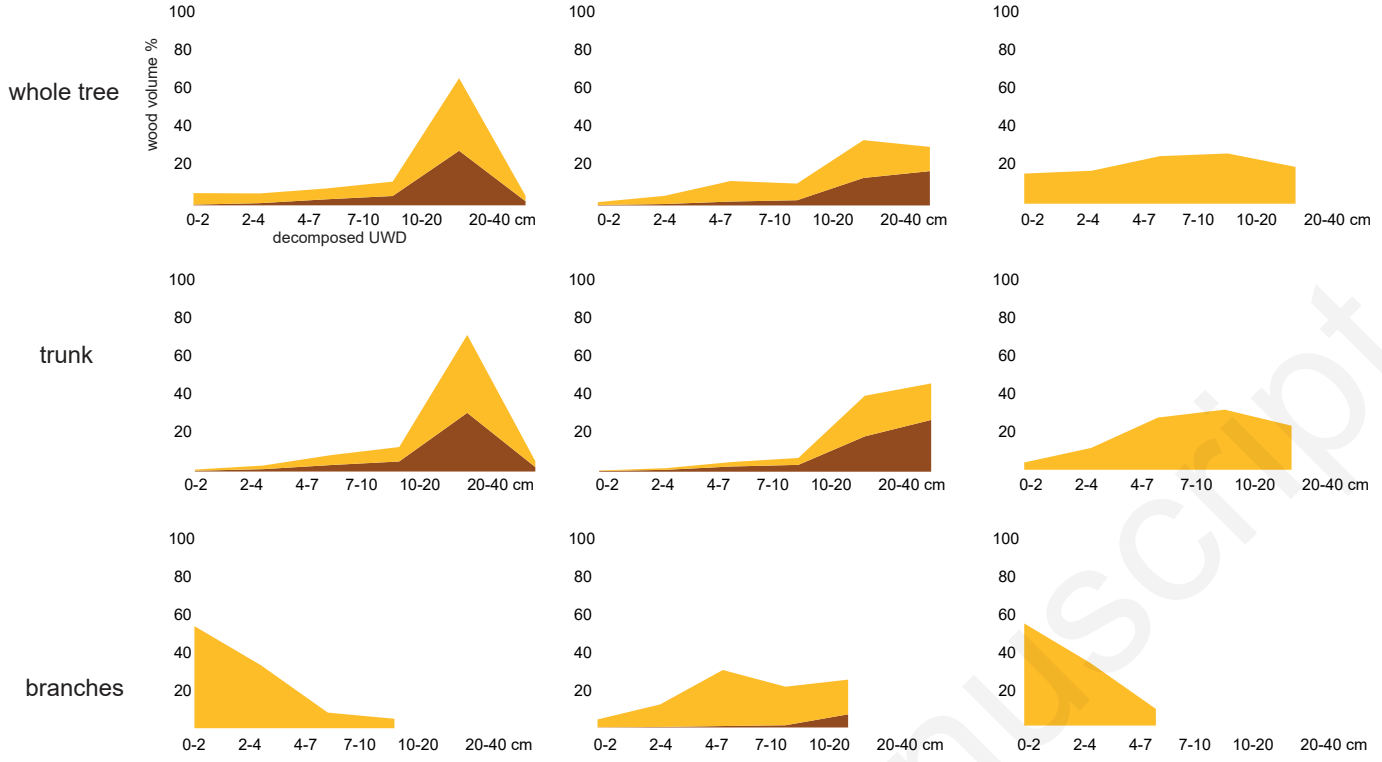
### Bois de l'or - seeded trees



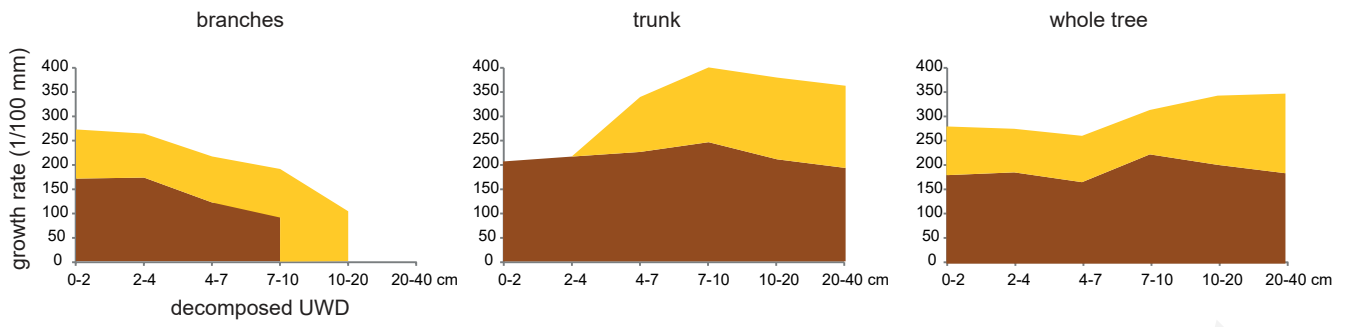
Cagouillères

Bogny-sur-Meuse

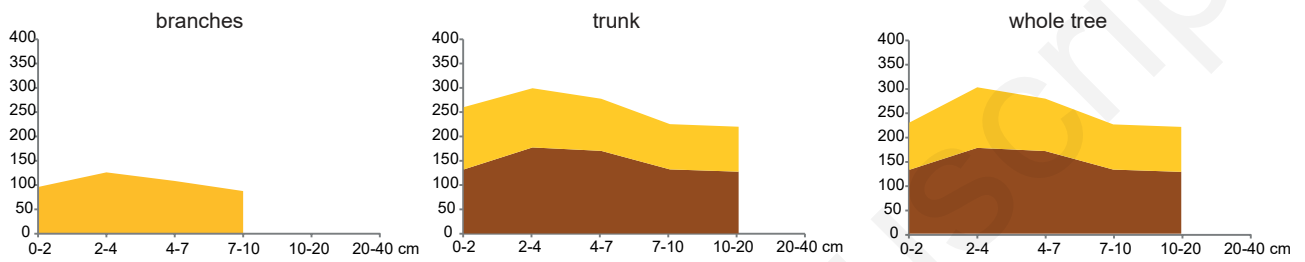
Bois de l'Or  
(seeded and coppiced trees)



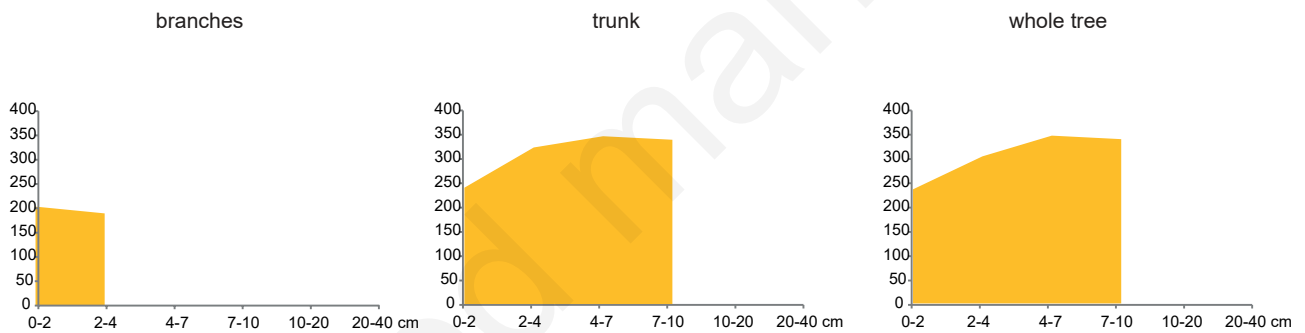
## Bogny-sur-Meuse



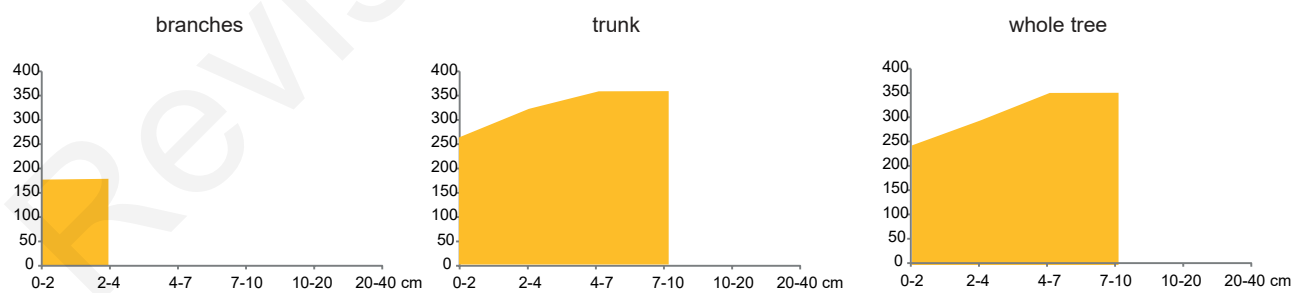
## Cagouillères



## Bois de l'Or- seeded trees



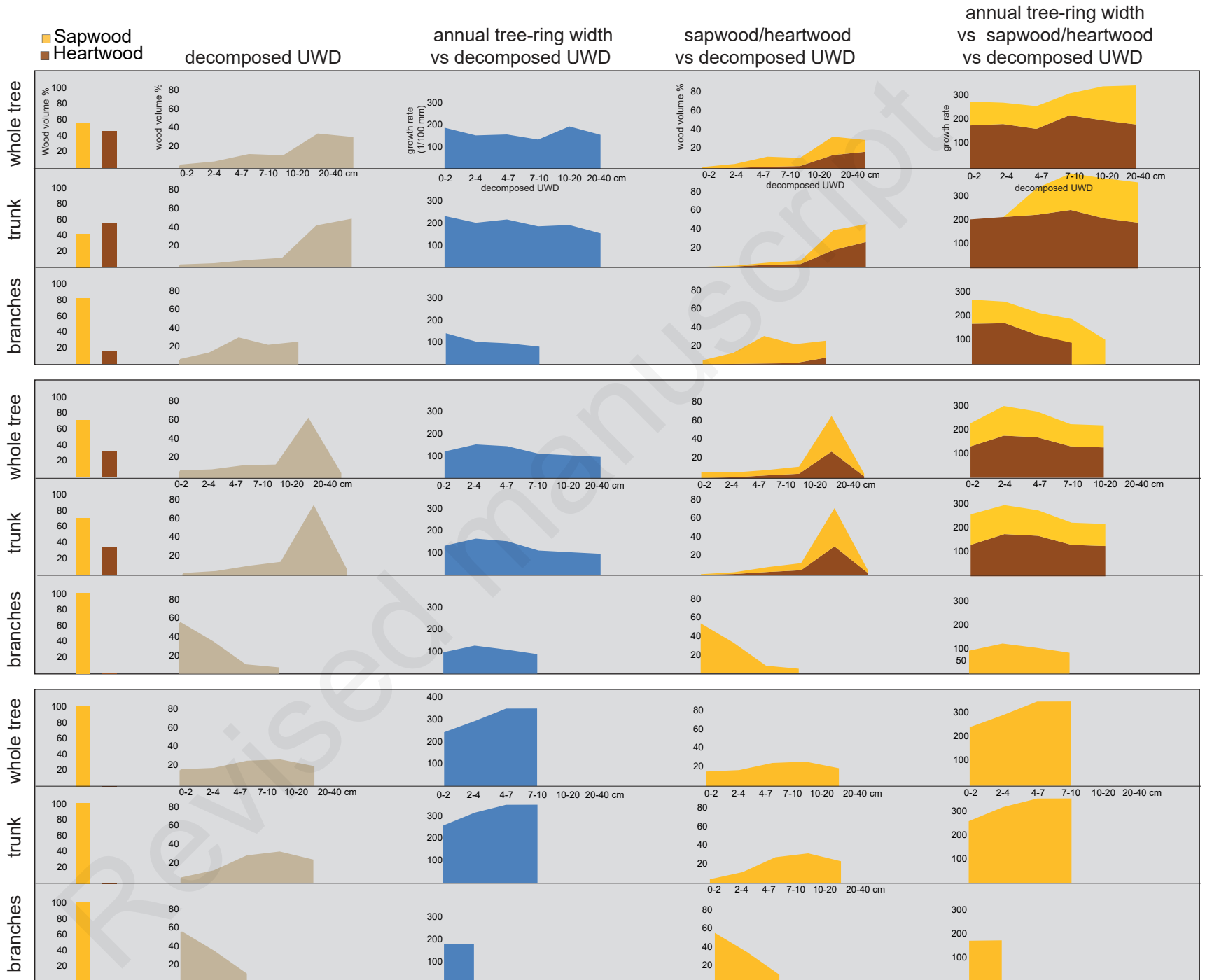
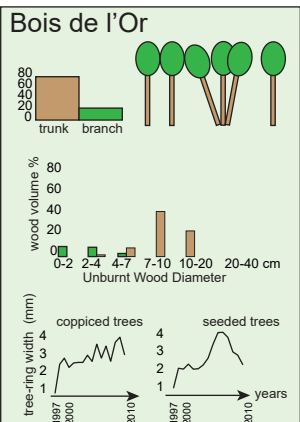
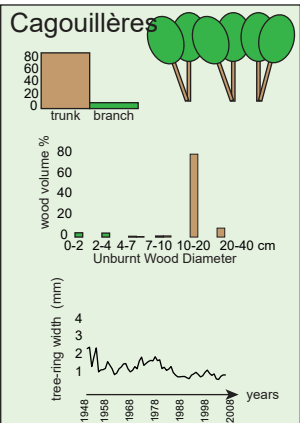
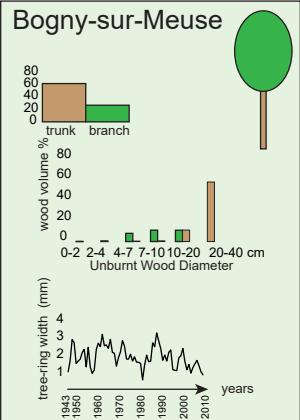
## Bois de l'Or- coppiced trees



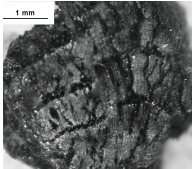

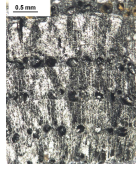

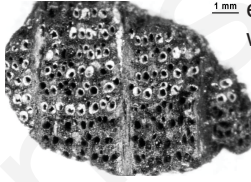
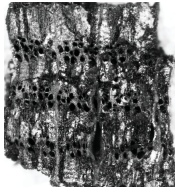
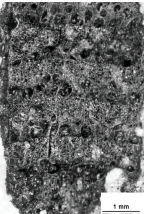
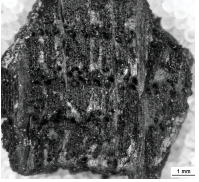
■ sapwood  
■ heartwood

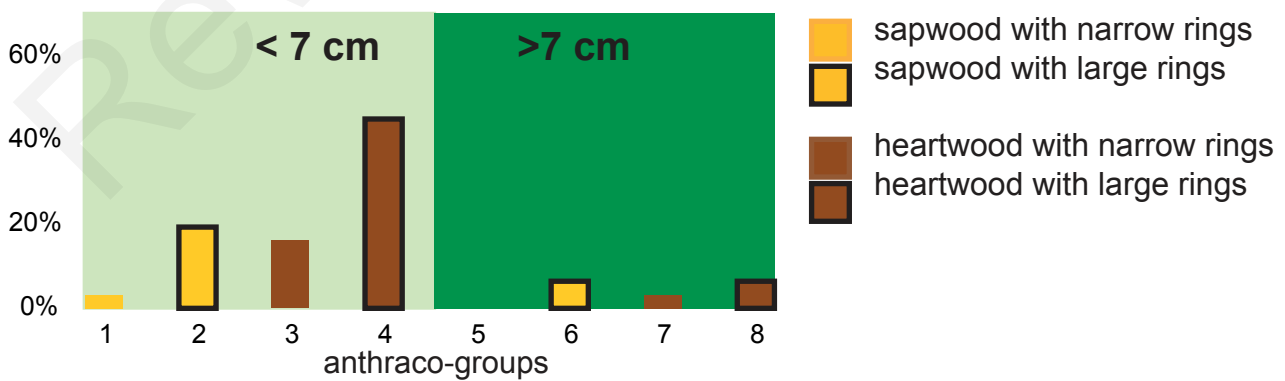


dendrological features of modern wood stand



# REGULAR WIDTH RINGS

charcoal-pith distance	heartwood/sapwood	tree-ring width	anthraco-groups	charcoal fragments
< 3.5 cm (diameter < 7 cm)	Sapwood	narrow rings	1	 young woods
		large rings	2	
	Heartwood	narrow rings	3	
		large rings	4	 internal part of mature woods
> 3.5 cm (diameter > 7 cm)	Sapwood	narrow rings	5	 external part of mature woods
		large rings	6	
	Heartwood	narrow rings	7	
		large rings	8	 middle part of mature woods



Dendrological characteristics		SITES			
		Le Bois de l'or	Bogny-sur-Meuse	Les Cagouillères	
Description		Self seeded and coppice trees	Dominant tree of a coppice-under-standard	Abandoned old coppice	
Age		< 15 years old	68 years old	About 60 years old	
Substratum		Brown soil on schists	Brown soil on schists	Calcareous plateau	
<i>Trees with a diameter less than 7.5 cm</i>	basal area increment (m <sup>2</sup> /ha)	6.4	2.7	–	
	stand density (number of stems /ha)	4924	2387	–	
	average square diameter (cm)	4.1	3.8	–	
<i>Trees with a diameter more than 7.5 cm</i>	basal area increment (m <sup>2</sup> /ha)	7.6	20	–	
	stand density (number of stems /ha)	1074	462	1300	
	average square diameter (cm)	9.5	23.5	–	
	dominant height (m)	9.1	22.2	18	
Sampled trees	description	coppice trees	self-seeded trees	Dominant tree	coppice trees
	number of sampled trees	5	5	1	4
	average square diameter at 1,3 m (cm)	10.4	10	30.6	20.75
	total height (m)	8.8	8.5	20.3	17.7
	ratio height/diameter (m/m)	84.6	85	66.	85.3
	height of the first large branch (m)	3.9	3.7	7.7	10
	height of the base of the crown (m)	3.1	3	8.5	10
	average square diameter of the crown (m)	5.7	5.5	7.3	–

Station	Tree	Regeneration	Disc reference	Organ	Height (m)	Age	Radius under bark (cm)	Heartwood width (cm)	Sapwood width (cm)	Number of sapwood tree rings
Bogny-sur-Meuse	Bog. 0		0a	trunk	1	68	13.43	10.09	3.34	18
	Bog. 0		0d	trunk	4	61	11.99	9.28	2.71	16
	Bog. 0		0f	trunk	6	52	11.41	8.86	2.55	15
	Bog. 0		0h1b	branch	–	45	5.44	3.61	1.83	26
	Bog. 0		0h1b1a	branch	–	43	4.78	2.35	2.43	29
	Bog. 0		0h1b1b	branch	–	40	4.06	0.00	4.06	40
	Bog. 0	dominant self-seeded tree	0h1ble	branch	–	30	2.74	0.00	2.74	30
	Bog. 0		0h1d	branch	–	39	4.44	2.52	1.92	22
	Bog. 0		0h1e	branch	–	36	4.49	2.09	2.41	20
	Bog. 0		0h1f	branch	–	32	3.75	0.00	3.75	32
	Bog. 0		0m1a	branch	–	38	3.41	0.00	3.41	38
	Bog. 0		0n	trunk	14	36	4.96	2.13	2.83	21
	Bog. 0		0n2a	branch	–	33	2.68	0.00	2.68	33
	Bog. 0		0n2b	branch	–	28	2.48	0.00	2.48	28
Cagouillères	Cag. A		A11A	trunk	11	41	4.71	1.32	3.39	34
	Cag. A		A17A	trunk	17	36	3.29	0.00	3.29	36
	Cag. A		A33A	branch	–	26	1.82	0.00	1.82	26
	Cag. B		B10C	trunk	10	36	5.42	2.86	2.56	23
	Cag. B		B1A	trunk	1	61	8.33	5.96	2.37	22
	Cag. B		B1C	trunk	1	60	8.49	5.65	2.84	23
	Cag. B		B2A	trunk	2	58	7.19	4.72	2.47	23
	Cag. B		B3. C	trunk	3	55	7.02	4.24	2.79	24
	Cag. B		B3A	trunk	3	57	7.18	4.57	2.61	24
	Cag. B		B48B	branch	–	23	1.93	0.00	1.93	23
	Cag. C		C2	trunk	2	60	6.08	3.37	2.70	22
	Cag. C	coppice trees	C2B	trunk	2	60	6.25	4.79	1.46	23
	Cag. C		C3A	trunk	3	55	6.12	4.62	1.50	23
	Cag. C		C48A	branch	–	30	3.33	1.02	2.31	22
	Cag. C		C51A	branch	–	18	2.13	0.00	2.13	18
	Cag. C		C52A	branch	–	14	1.72	0.00	1.72	14
	Cag. C		C5A	trunk	5	46	5.60	4.03	1.57	22
	Cag. C		C8C	trunk	8	37	4.98	3.32	1.66	21
	Cag. D		D10A	trunk	10	48	6.28	3.48	2.80	31
	Cag. D		D13A	trunk	13	38	3.96	0.75	3.21	29
	Cag. D		D3C	trunk	3	61	8.45	5.61	2.84	36
	Cag. D		D47A	branch	–	19	2.49	0.00	2.49	19
Cag. D		D47B	branch	–	20	2.89	0.00	2.89	20	

Station	Tree	Regeneration	Disc reference	Organ	Height (m)	Age	Radius under bark (cm)	Heartwood width (cm)	Sapwood width(cm)	Number of sapwood tree rings
Bois de l'Or	Boi.10		10A.A	Trunk	1	14	4.17	0	4.17	14
	Boi.10		10B.A	Trunk	2	12	3.43	0	3.43	12
	Boi.10		10C.A	Trunk	3	11	2.84	0	2.84	11
	Boi.10		10D.A	Trunk	4	9	2.62	0	2.62	9
	Boi.10		10E.A	Trunk	5	7	1.59	0	1.59	7
	Boi.10		10F.A	Trunk	6	5	0.92	0	0.92	5
	Boi.13		13A.A	Trunk	1	15	4.16	0	4.16	15
	Boi.13		13B.A	Trunk	2	12	3.52	0	3.52	12
	Boi.13		13C.A	Trunk	3	11	3.44	0	3.44	11
	Boi.13		13D.A	Trunk	4	9	3.07	0	3.07	9
	Boi.13		13E.A	Trunk	5	8	2.27	0	2.27	8
	Boi.13		13F.A	Trunk	6	6	1.96	0	1.96	6
	Boi.13		13G.A	Trunk	7	4	2.75	0	2.75	4
	Boi.13		13G-1A B c	branch	-	6	1.33	0	1.33	6
	Boi.14		14A.A	Trunk	1	14	4.19	0	4.19	14
	Boi.14		14B.A	Trunk	2	11	3.60	0	3.60	11
	Boi.14		14C.A	Trunk	3	9	3.01	0	3.01	9
	Boi.14	seeded trees	14D.A	Trunk	4	8	2.82	0	2.82	8
	Boi.14		14E.A	Trunk	5	6	2.59	0	2.59	6
	Boi.14		14F.A	Trunk	6	7	2.60	0	2.60	7
	Boi.14		14G.A	Trunk	7	4	1.44	0	1.44	4
	Boi.14		14D-2A B c	branch	-	8	1.56	0	1.56	8
	Boi.17		17A.A	Trunk	1	14	4.85	0	4.85	14
	Boi.17		17B.A	Trunk	2	12	2.97	0	2.97	12
	Boi.17		17C.A	Trunk	3	11	2.85	0	2.85	11
	Boi.17		17D.A	Trunk	4	9	2.43	0	2.43	9
	Boi.17		17E.A	Trunk	6	7	1.49	0	1.49	7
	Boi.17		17E-1A	branch	-	8	1.96	0	1.96	8
	Boi.17		17F.A	Trunk	6	5	1.32	0	1.32	5
	Boi.17		17G.A	Trunk	7	4	0.89	0	0.89	4
	Boi.19		19A.A	Trunk	1	13	4.29	0	4.29	13
	Boi.19		19B.A	Trunk	2	12	3.61	0	3.61	12
	Boi.19		19C.A	Trunk	3	9	3.43	0	3.43	9
	Boi.19		19D.A	Trunk	-	8	2.95	0	2.95	8
	Boi.19		19E.A	Trunk	5	7	2.22	0	2.22	7
	Boi.19		19F.A	Trunk	6	5	1.62	0	1.62	5
	Boi.19		19C-2A	branch	4	9	1.22	0	1.22	9
	Boi.11		11A.A	Trunk	1	16	4.72	0	4.72	16
	Boi.11		11B.A	Trunk	2	14	3.55	0	3.55	14
	Boi.11		11C.A	Trunk	3	12	3.52	0	3.52	12
	Boi.11		11D.A	Trunk	4	10	2.91	0	2.91	10
	Boi.11		11E.A	Trunk	5	8	2.18	0	2.18	8
	Boi.11		11F.A	Trunk	6	6	1.70	0	1.70	6
	Boi.11		11G.A	Trunk	7	4	2.92	0	2.92	4
	Boi.11		11E-3A A c	branch	-	9	1.48	0	1.48	9
	Boi.12		12A.A	Trunk	1	14	4.58	0	4.58	14
	Boi.12		12B.A	Trunk	2	14	4.10	0	4.10	14
	Boi.12		12C.A	Trunk	3	12	3.91	0	3.91	12
	Boi.12		12D.A	Trunk	4	10	3.41	0	3.41	10
	Boi.12		12E.A	Trunk	5	8	3.61	0	3.61	8
	Boi.12		12F.A	Trunk	6	6	2.28	0	2.28	6
	Boi.12		12G.A	Trunk	7	5	1.23	0	1.23	5
	Boi.12		12H.A	Trunk	8	4	0.85	0	0.85	4
	Boi.12		12E-1A D c	branch	-	9	1.30	0	1.30	9
	Boi.15		15A.A	Trunk	1	14	3.99	0	3.99	14
	Boi.15		15B.A	Trunk	2	12	3.49	0	3.49	12
	Boi.15	coppice trees	15C.A	Trunk	3	11	3.15	0	3.15	11
	Boi.15		15D.A	Trunk	4	8	1.87	0	1.87	8
	Boi.15		15E.A	Trunk	5	6	1.30	0	1.30	6
	Boi.15		15F.A	Trunk	6	4	0.84	0	0.84	4
	Boi.15		15D-1A	branch	-	8	1.66	0	1.66	8
	Boi.16		16A.A	Trunk	1	14	4.36	0	4.36	14
	Boi.16		16B.A	Trunk	2	13	3.94	0	3.94	13
	Boi.16		16C.A	Trunk	3	12	3.56	0	3.56	12
	Boi.16		16D.A	Trunk	4	9	3.14	0	3.14	9
	Boi.16		16E.A	Trunk	5	13	3.69	0	3.69	13
	Boi.16		16F.A	Trunk	6	11	2.80	0	2.80	11
	Boi.16		16G.A	Trunk	7	4	1.10	0	1.10	4
	Boi.16		16E-3A	branch	-	8	1.14	0	1.14	8
	Boi.18		18A.A	Trunk	1	13	4.05	0	4.05	13
	Boi.18		18B.A	Trunk	2	12	4.25	0	4.25	12
	Boi.18		18C.A	Trunk	3	11	3.34	0	3.34	11
	Boi.18		18D.A	Trunk	4	10	3.09	0	3.09	10
	Boi.18		18E.A	Trunk	5	8	2.13	0	2.13	8
	Boi.18		18E-3A	branch	-	8	1.82	0	1.82	8
	Boi.18		18F.A	Trunk	6	6	1.34	0	1.34	6
	Boi.18		18G.A	Trunk	7	5	1.17	0	1.17	5