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Abstract

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

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

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

1. Introduction

1.1. Anthracology and past woodland reconstruction

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

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

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

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

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

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

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

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

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

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

2.2. The pith estimation tool

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

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

2.3. The analysis diameter tool (ADmodel)

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

2. Material and Method

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

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

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

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

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

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

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

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

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

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

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

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

The last combination is the association of all the dendro-anthracological parameters: heartwood/sapwood, tree-ring width and diameters. Besides the distinction between young and mature woods based on the association between heartwood/sapwood and diameters, it becomes possible to discriminate branches from trunks among young woods. Indeed, 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.

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

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

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

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

iv) Shrinkage during charcoalification leads to lower tree-ring width. This process is not consistent, depending on sapwood/heartwood and charcoal-pith distance. A preliminary study on shrinkage offers promising results in order to propose correction factors (Garcia Martinez and Dufraisse, 2012).

v) The relative frequency of the different taxa in charcoal assemblages is representative of the used biomass (wood volume). In the same way, the use of the dendro-anthracological parameters is based on the assumption that charcoal fragments represent the different parts of trees proportionally to their volume, with their dendrological characteristics (growth, ratio sapwood/heartwood, diameter). That is why the ADmodel is based on wood volume (and not on the number of fragments). However, we stress that, this model cannot reconstruct the quantity of initially burnt wood.

vi) As for the interpretation of tree-ring width (Marguerie, 1992, p. 72; Marguerie and Hunot, 2007), several conditions are required to interpret the dendro-anthracological parameters: charcoal assemblages must come from numerous trees, tree-ring series are randomly distributed in the transversal sections of charcoal fragments, ring series must be numerous enough and with a homogeneous width, acquisitions areas are subjected to the same climatic influences and the geological substratum must be homogeneous.

5. Conclusion

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

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

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

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

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Captions

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

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

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

Fig. 1. Dendro-anthracological tools.

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

Fig. 3. Location of sampled stands.

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

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.

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

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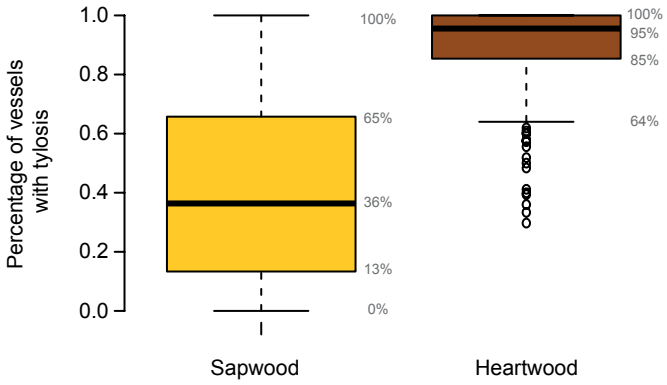
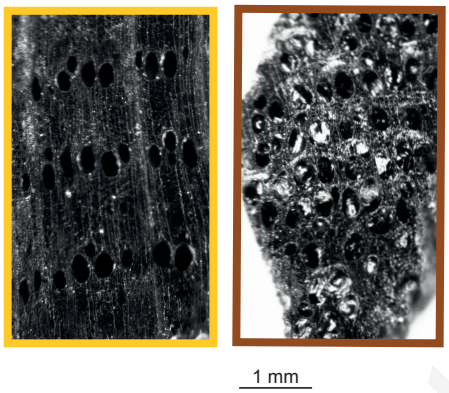
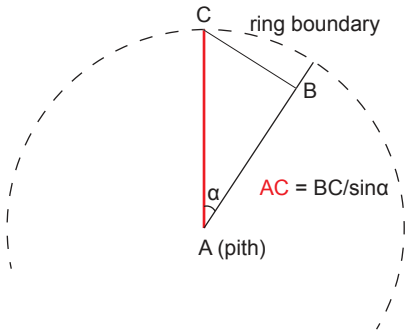
a- Heartwood-Sapwood discriminating tool

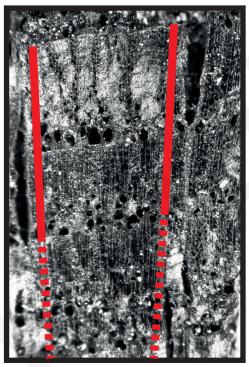




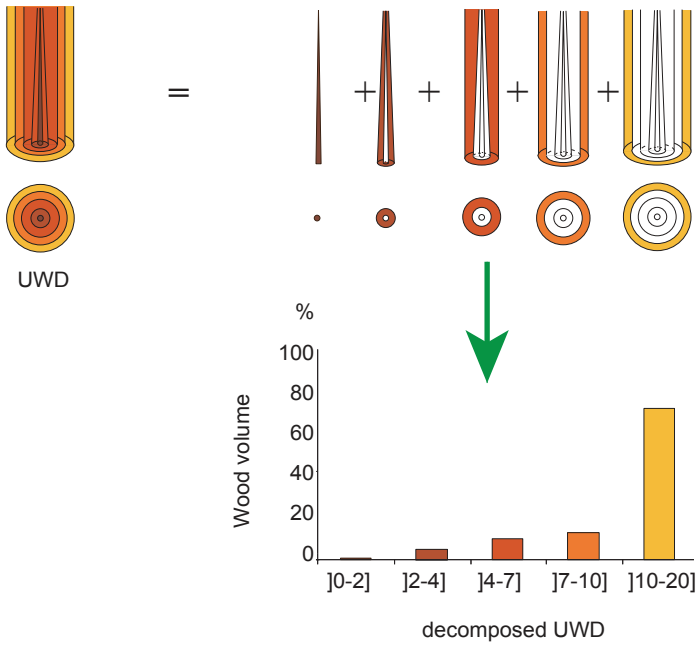
b- Pith estimation tool



α : angle between 2 ligneous rays
BC : distance between 2 ligneous rays
AC : pith-charcoal distance



c- Analysis Diameter tool



Oak modern-day stands
characterization sampling

dendrometrical plan
composition, structure, density, regeneration

logs
measurements

wood discs
Tree-ring measurements

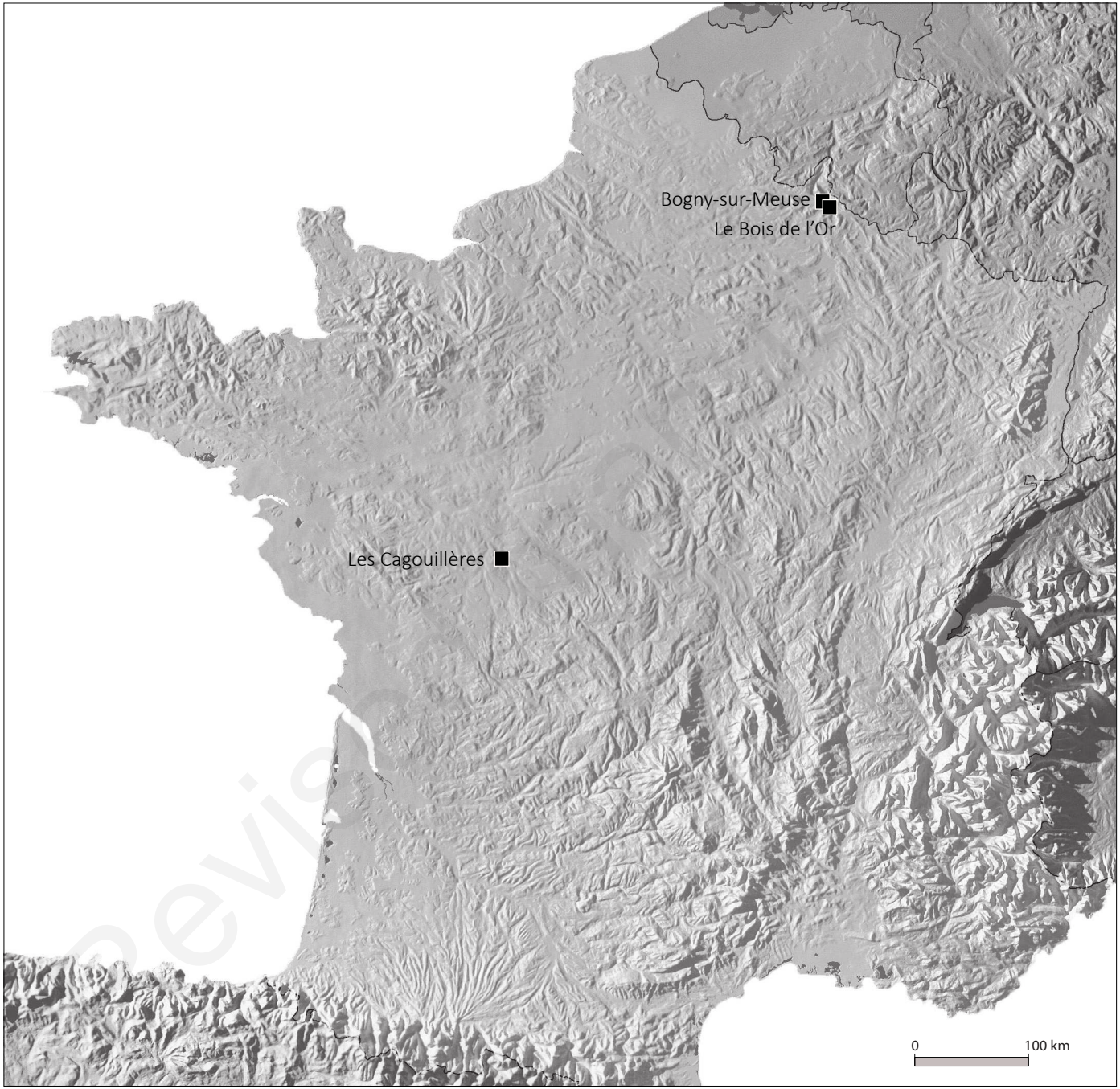
dendrological reference dataset

experimental charcoal assemblages

carbonized wood discs

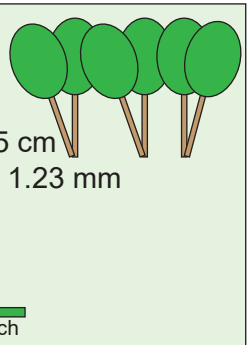
dendro-anthracological tools
Pith location, heartwood/sapwood discrimination, modelling diameter

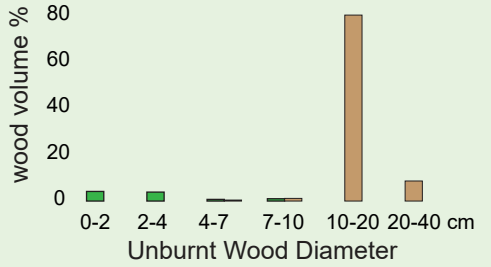
anthracological dataset

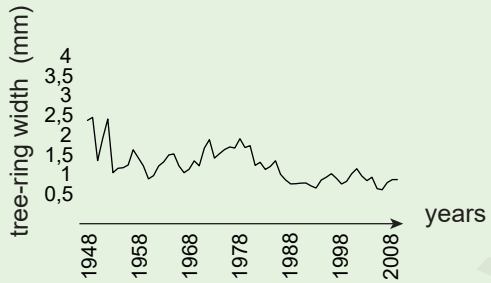

Bogny-sur-Meuse
Le Bois de l'Or
Les Cagouillères
0
100 km

Les Cagouillères

Abandonned old coppice
4 trees
Average age = 62 yr
Average diameter = 20.75 cm
Average tree-ring width = 1.23 mm

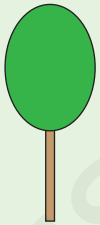


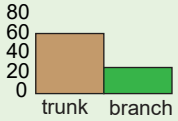


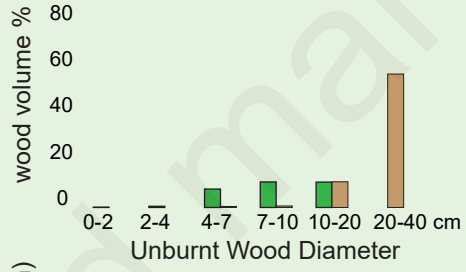


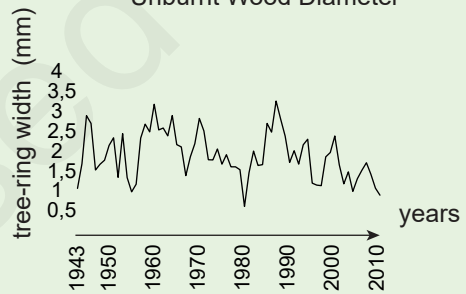
Bogny-sur-Meuse

Dominant standard
1 tree
Age = 68 yr
Diameter = 33 cm
Average tree-ring width = 1.35 mm



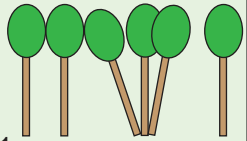


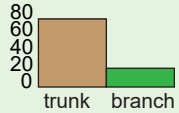


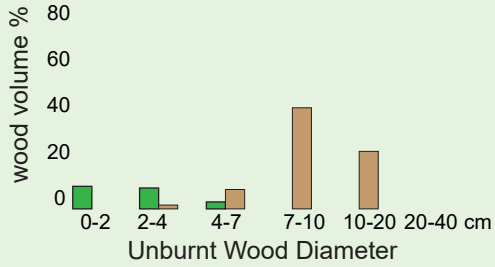


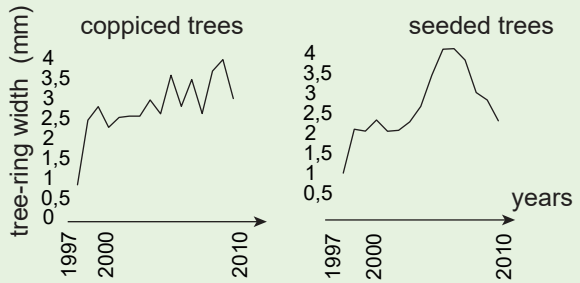
Bois de l'Or

Mixture of seeded and
coppiced trees
Average age = 14 yr
Average diameter = 10.21 cm
Average tree-ring width = 2.99 mm









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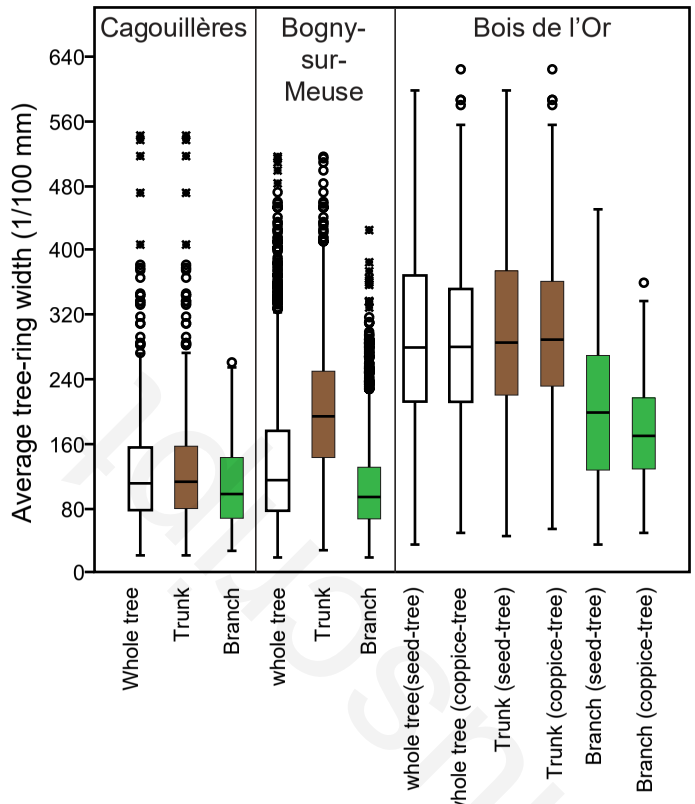

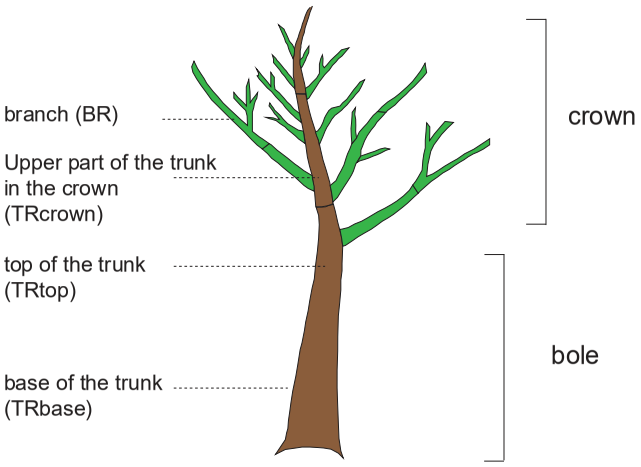

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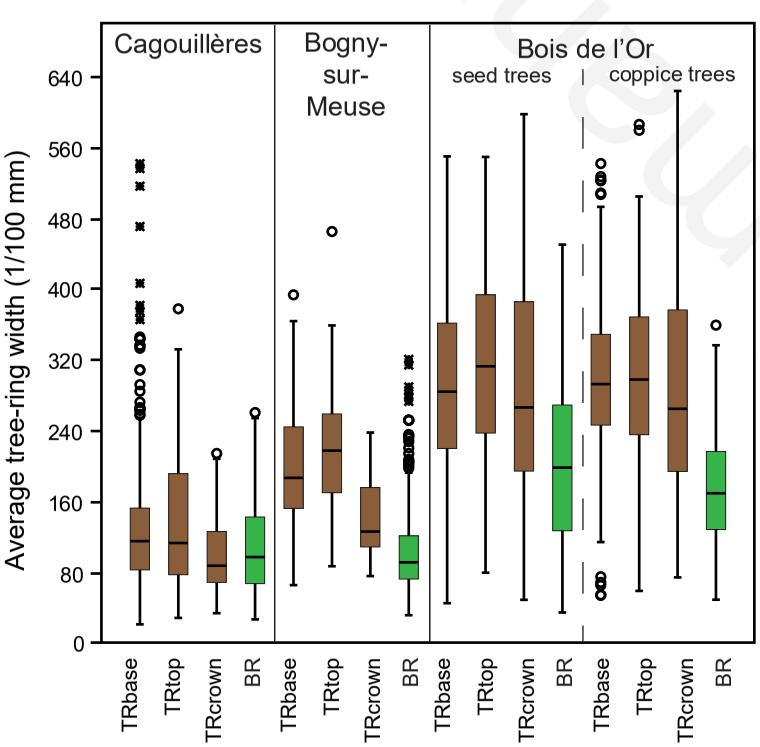
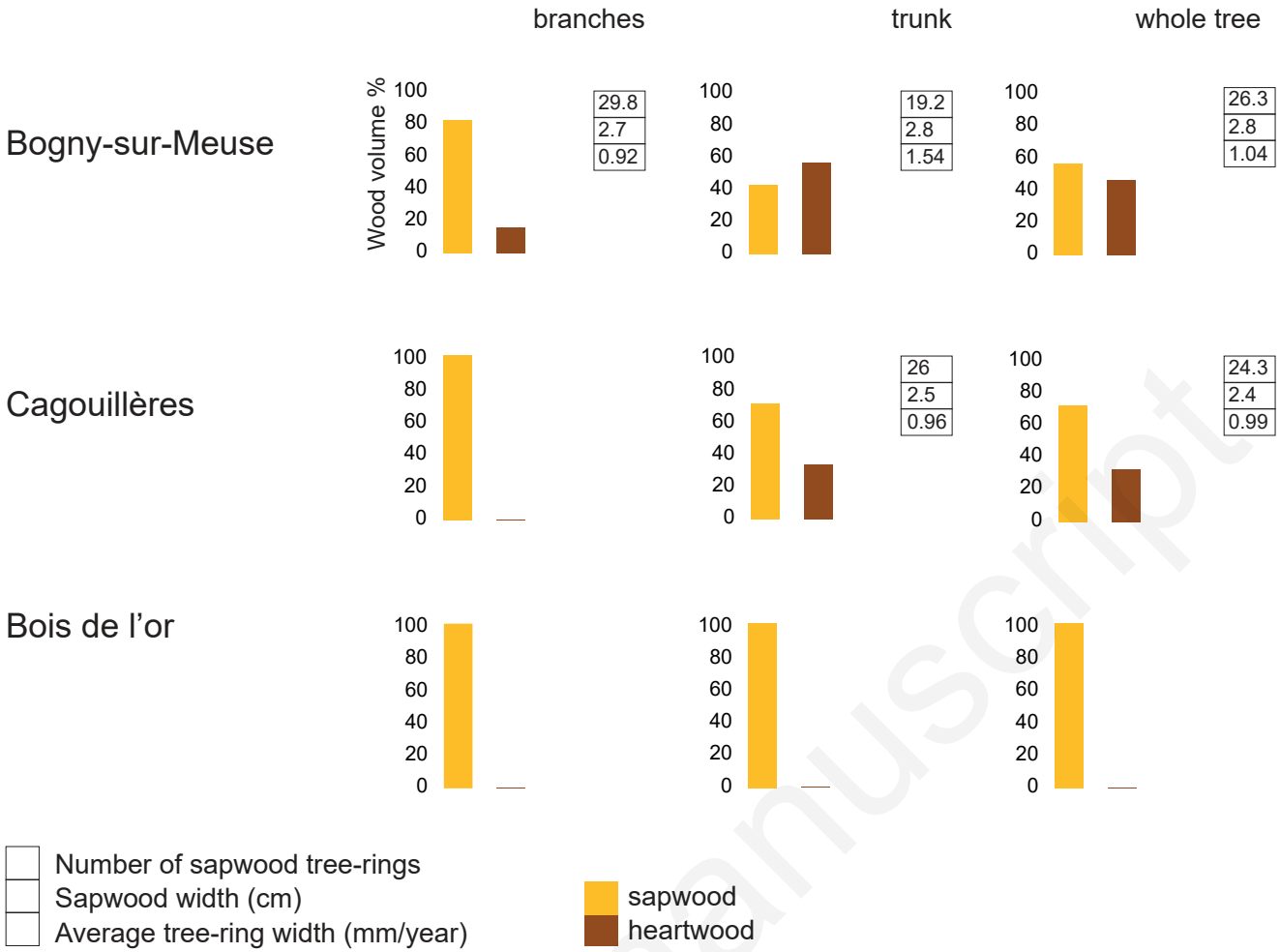
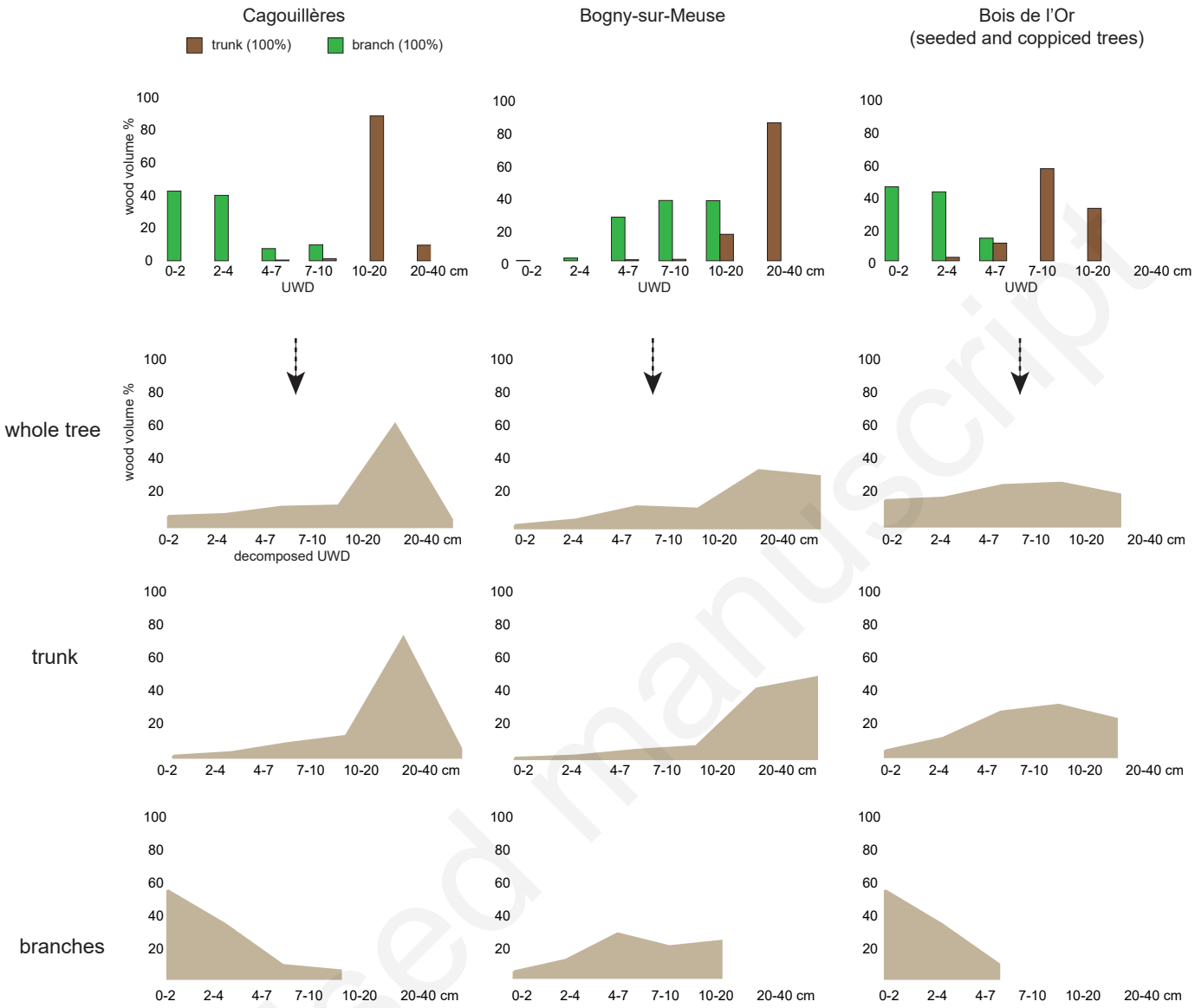
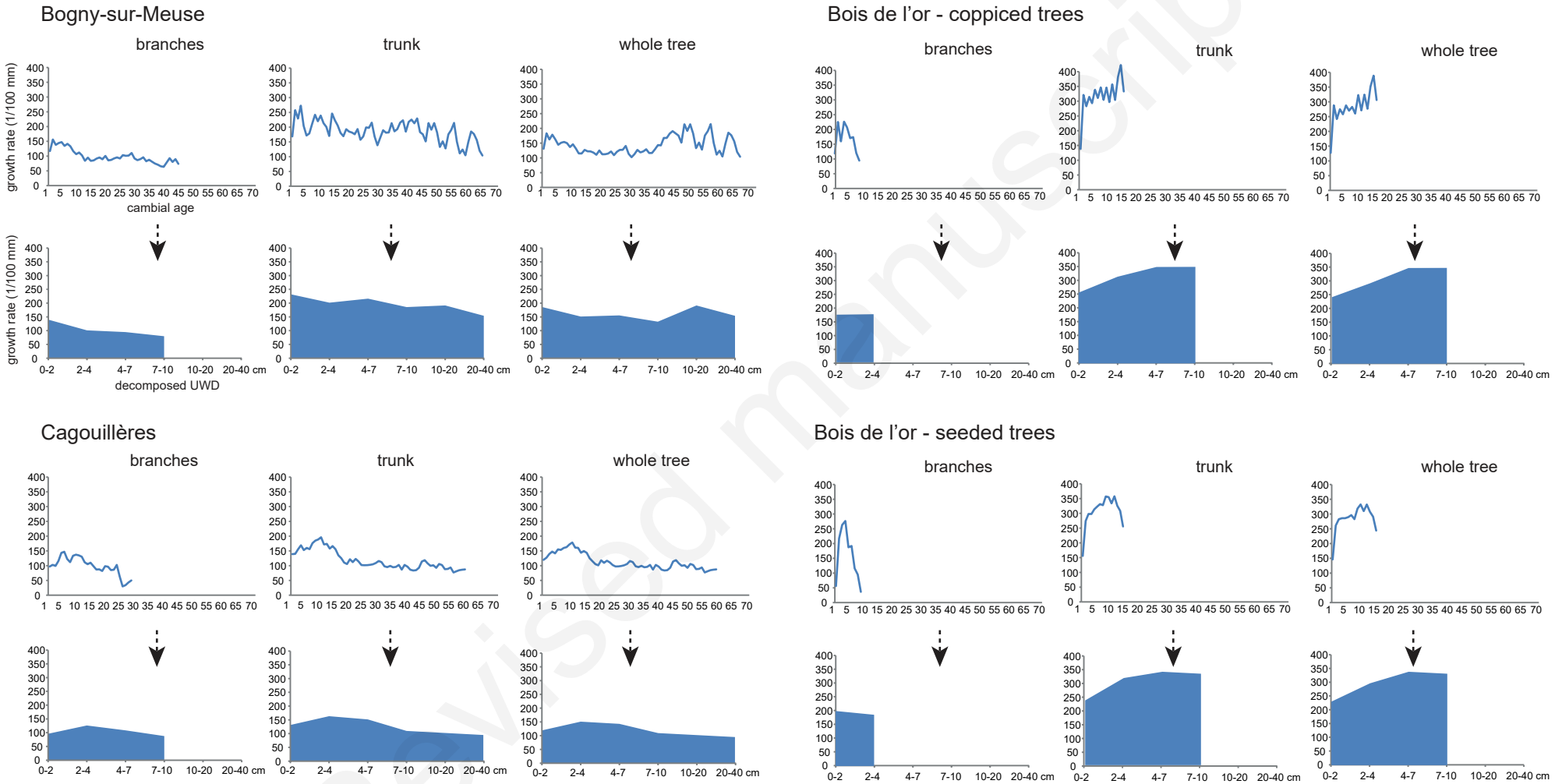
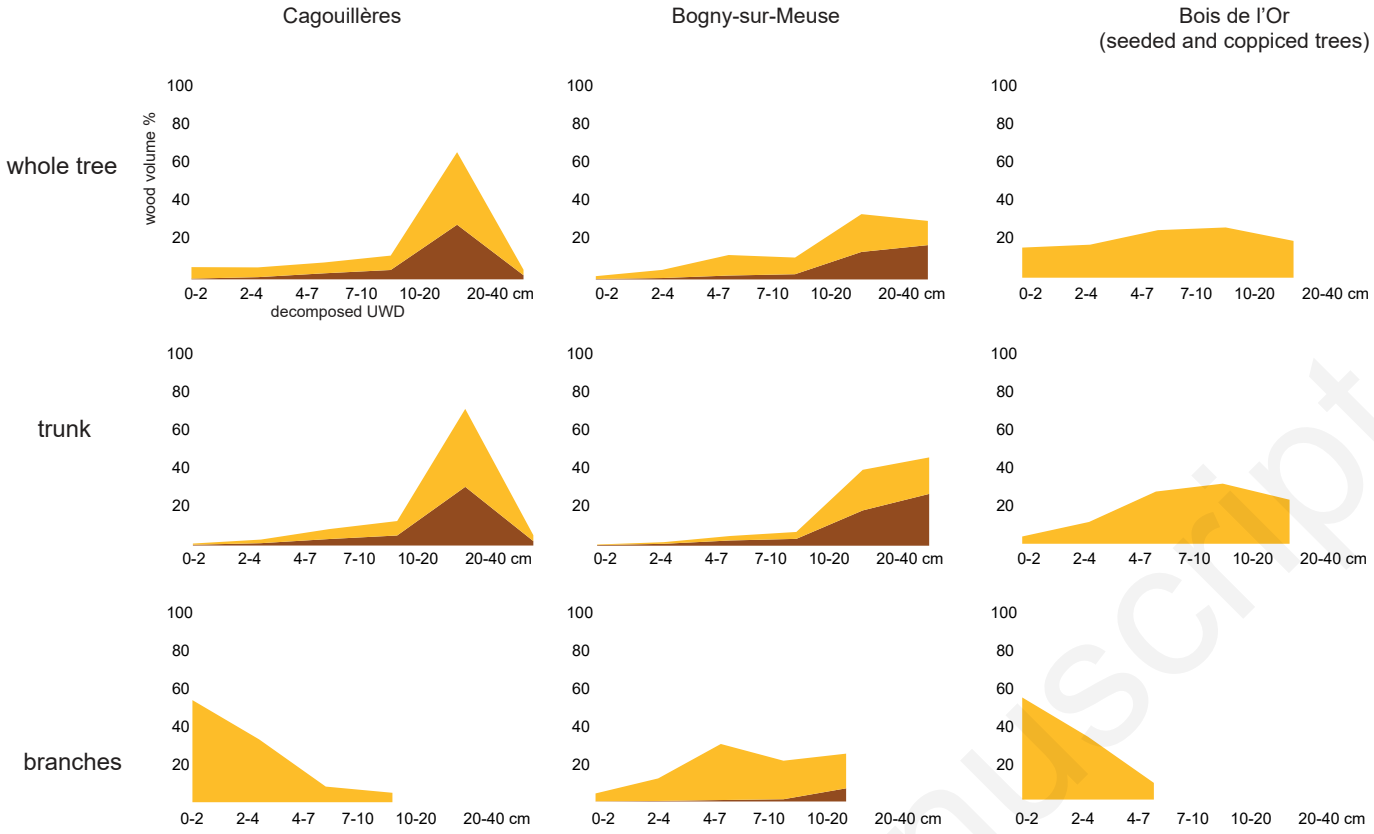


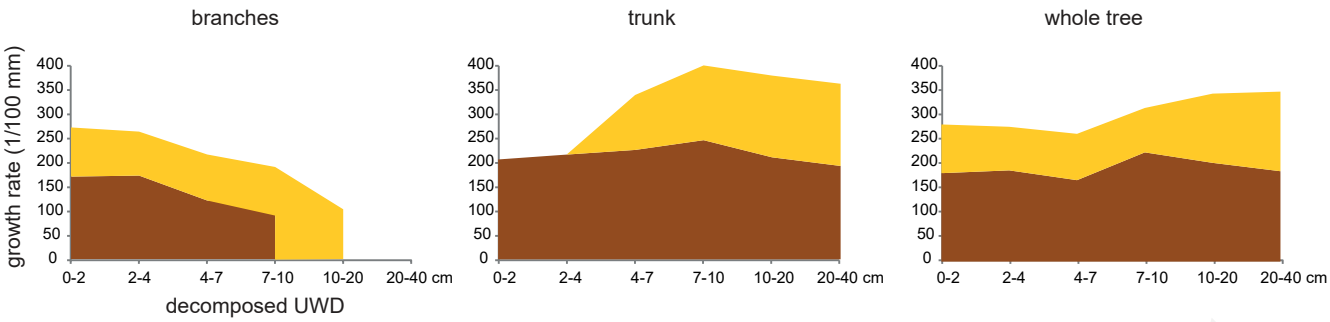




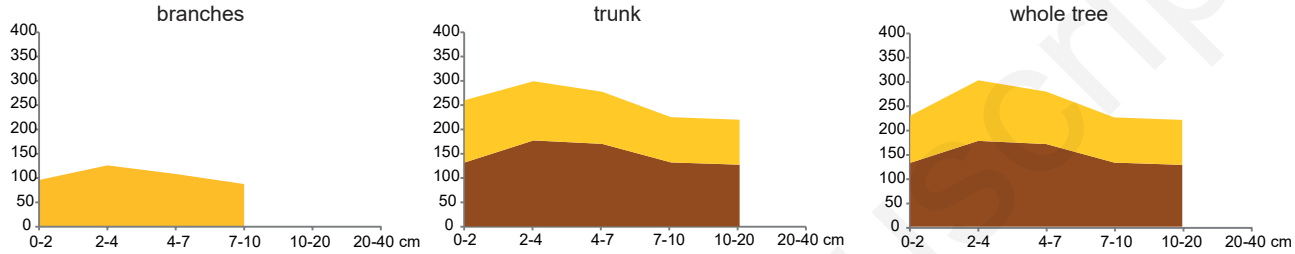




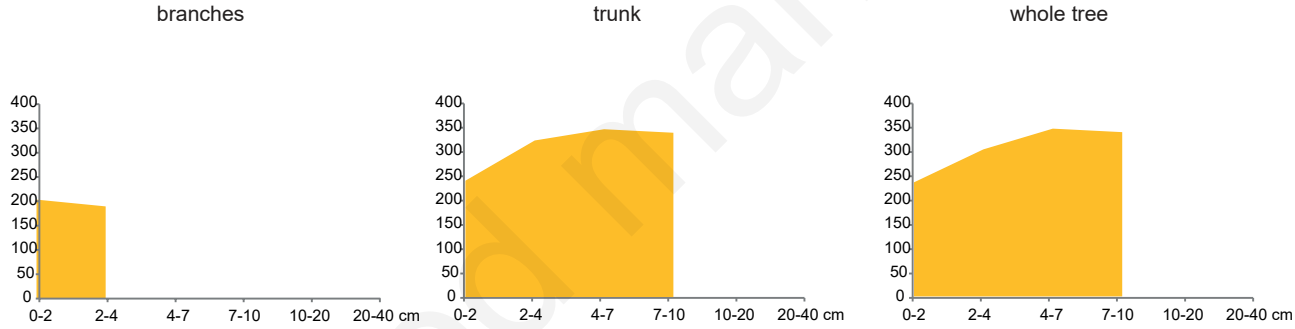
Bogny-sur-Meuse



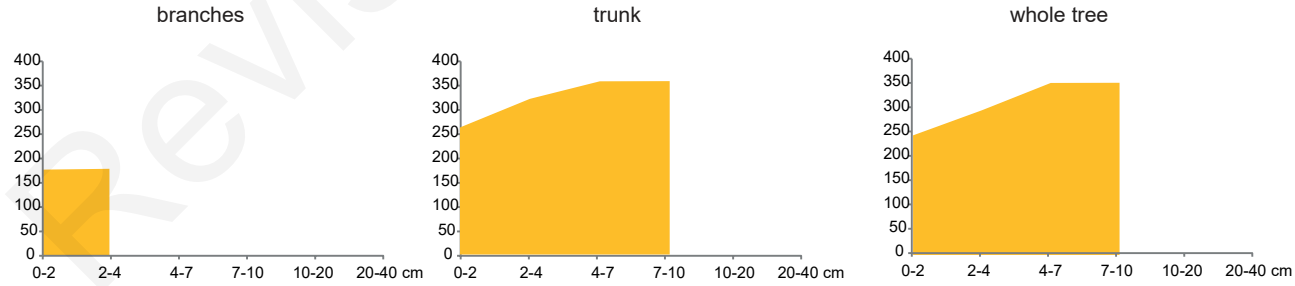
Cagouillères

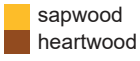


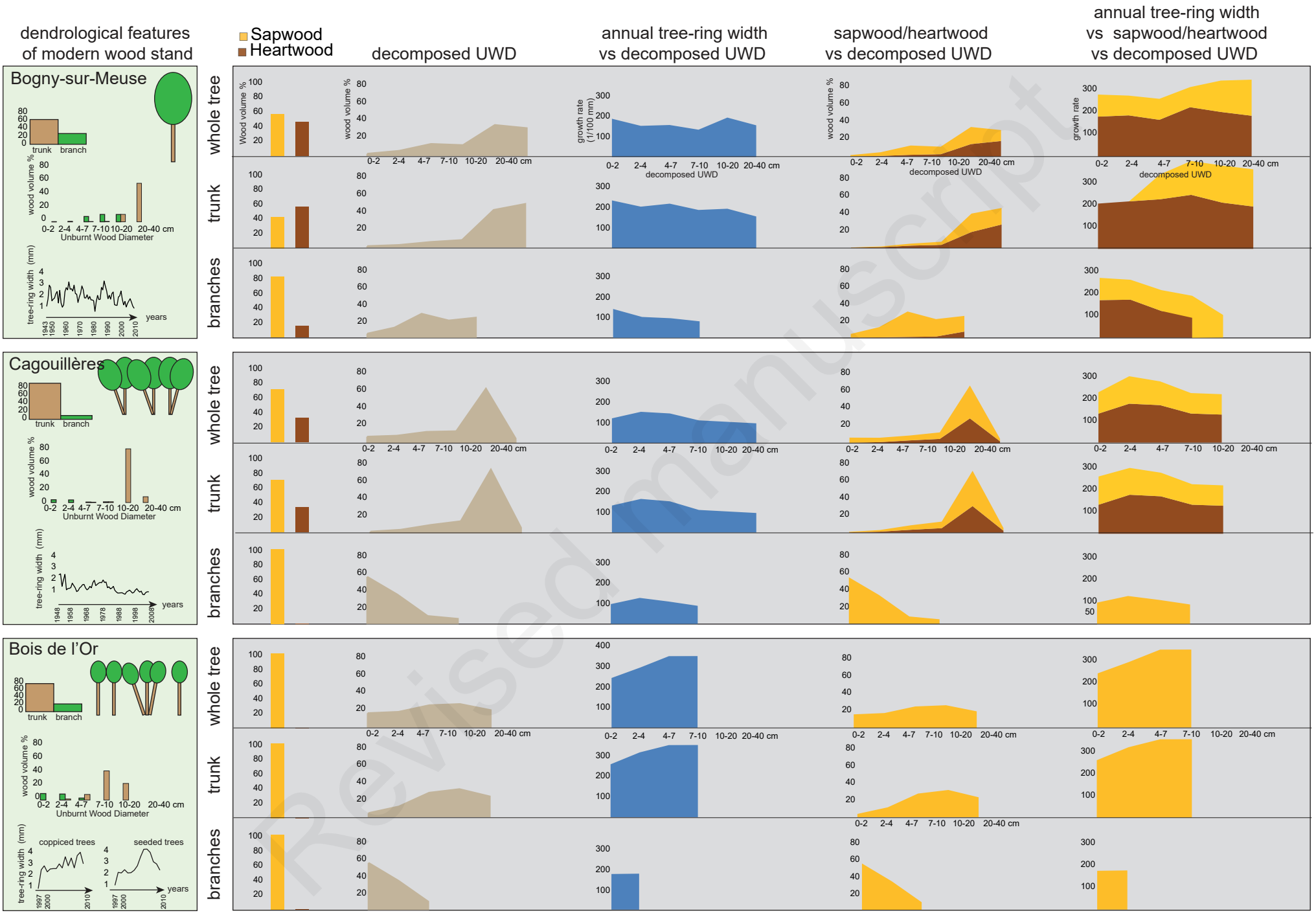
Bois de l'Or- seeded trees



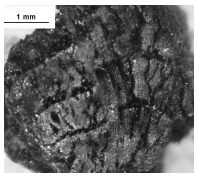
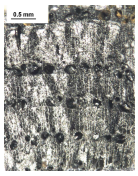
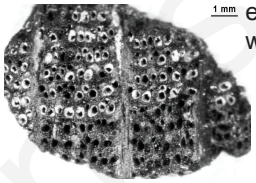
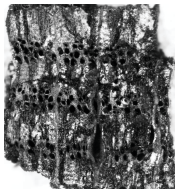
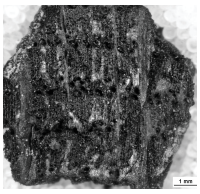
Bois de l'Or- coppiced trees

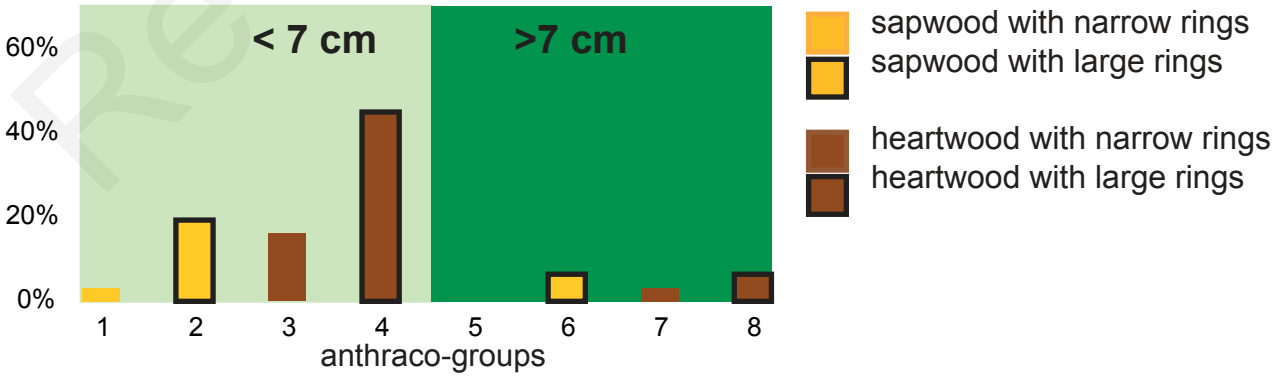






REGULAR WIDTH RINGS

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	 middle part of mature woods
		large rings	8	



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
Trees with a diameter less than 7.5 cm	basal area increment (m^2/ha)	6.4	2.7	_
	stand density (number of stems /ha)	4924	2387	_
	average square diameter (cm)	4.1	3.8	_
Trees with a diameter more than 7.5 cm	basal area increment (m^2/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	0h1b1e	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		14D.A	Trunk	4	8	2.82	0	2.82	8
	Boi.14	seeded trees	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