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Dendro-archaeological contribution to the history of forest exploitation. The case of the Gallo-Roman settlement of Oedenburg (Alsace, France) between 10 and 180 AD

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Key words forest structure / Gallo-Roman logging / dendro-typology / age growth trend / *Quercus* sp.

Summary

Dendrochronology has never been considered as simply a dating tool. In addition to the dates, which are always based on a regional scale signal, tree-ring series can provide information about forest structure and woodland development. Our study of the settlement of Oedenburg, established in the Rhine Limes of the Roman Empire, was conducted within this framework. The dated series provide a description of some structural aspects of oak-stands that were exploited for construction. In this aim, the analytic tools employed are “age trend patterns” and series classification or dendro-typology. The archaeological series were also compared to modern forest characteristics.

Throughout the chronology, woodland development appears dominated by two stages. The first is oak tree harvest. We observe that (1) series patterns from a single archaeological structure are more similar than between structures, and (2) wide tree rings are present during the juvenile phase. These rings are wider than those observed consecutively in modern logging. The effect of oak tree harvesting is local high-forest clearing. During the second stage, the high forest is in the process of recovery. After a few years of aging, Gallo-Roman oak ring width becomes sharply inferior to that observed in the actual forest. This can be explained by the high degree of competition between trees due to a poor thinning grade during recovery.

Within the chronology, stands were first exploited using a harvest and recovery system; second, supply may have focused

on preserved trees; and third, the regeneration rate was respected, but harvest age was lowered, resulting in stronger thinning of a stand, although they appear denser than present day managed high forests.

Introduction

Archaeological excavations, whether in relation to construction works (Laurelut *et al.*, 2007; Tegel and Vanmoerkerke, 2008) or programmed (Reddé *et al.*, 2005; Barral and Richard, 2009), have brought to light many wood samples from the Latinian and Gallo-Roman periods in the east of France. Dendrochronological dating of these samples has enabled the construction of site chronologies (Girardclos and Lambert, 1995) and regional references (Durost, 2005; Laurelut *et al.*, 2007) useful for the dating of new sites in this and neighbouring regions. However, dendrochronologists have never considered dendrochronology to be only a tool for dating wood. Annual production of wood depends on a complex system of ecological factors. In addition to the dates obtained, series of ring widths may be closely examined with several objectives in view (Munaut, 1979; Lambert, 1998). For the archaeologist, chronological information is of the greatest interest, but the corpus of archaeological woods also makes it possible to address climatic questions (Durost, 2005; Durost *et al.*, 2008; Rossignol and Durost, this volume) and the origin

of wood commerce (Fraiture, 2009; and see chapter “Trade” in this volume); it also provides information on forest history and management in different periods (Billamboz, 2003; Haneca *et al.*, 2005; 2006; Bernard *et al.*, 2007; 2008). More generally, a specialisation in “dendro-archaeology” is developing for which the objective is *the investigation of the interference between humans and the environment in prehistoric and historic times by using information from tree rings* (Sass-Klaassen, 2002).

Our study of the Gallo-Roman settlement of Oedenburg, established on the Rhine Limes, was conducted within this context. We present the development of the characteristics of “good building oaks” used at Oedenburg during the first two centuries AD and extract from the dated samples information on the original forest populations and on wood production practices. This approach is based on the classification of growth series: a dendro-typology (Billamboz, 2003), according to archaeological structures and by comparison of the age trend patterns in Gallo-Roman oaks and current forests for which the silviculture is known (Haneca *et al.*, 2005).

Dendrochronological results at the Biesheim site

The site

The Gallo-Roman settlement of Oedenburg is located within the present-day communities of Biesheim and Künheim in Alsace, in a border region between Germany and France (Fig. 1). The site, found in the northern part of the territory of a Celtic people, the Rauriques, along the Roman fortifications known as the *Limes*, on the left bank of the Rhine, extends onto the alluvial

flood plain as well as onto the alluvial terrace in Altkirch. As far as is currently known, woods dating from 3–4 AD constitute the first evidence of occupation in the area. They were found at the edge of an important religious complex that progressively developed throughout the first century AD, beginning with the end of the Augustinian period. It was under Tiberius, no later than *ca* 30 AD, but perhaps as early as 14–20 AD, that soldiers settled here, building a camp of approximately 3.5 ha alongside an active channel of the Rhine (Reddé, 2009). Its existence was well noted until around 69 or 70 AD after which the *Limes* were moved to beyond the Black Forest, south Germany. Constructions from late Antiquity and the High Middle Ages were concentrated within flood-safe zones, thus depriving us of wood material.

With the beginnings of a military presence, a civilian settlement also developed which is now better known to us through specific excavations and via a vast geophysical survey (Reddé *et al.*, 2005). Most of the structures on the alluvial plain are linked to the phases of construction and re-building during the first two centuries AD. Seven sectors in close proximity to palaeochannels and partially under water during the antique period, have furnished samples of archaeological wood of different species, particularly oak (*Quercus robur / petraea*), fir (*Abies alba*), alder (*Alnus glutinosa*), elm (*Ulmus* sp.), willow (*Salix* sp.) and poplar (*Populus* sp.). The results presented are from 177 dated oaks belonging to different archaeological structures. Sectors 9 and 10 on either side of the Riedgraben channel contain most of the woods used in the development of quay facilities (sector 9) or a pool and its adjoining spaces in sector 10 (Fig. 1).

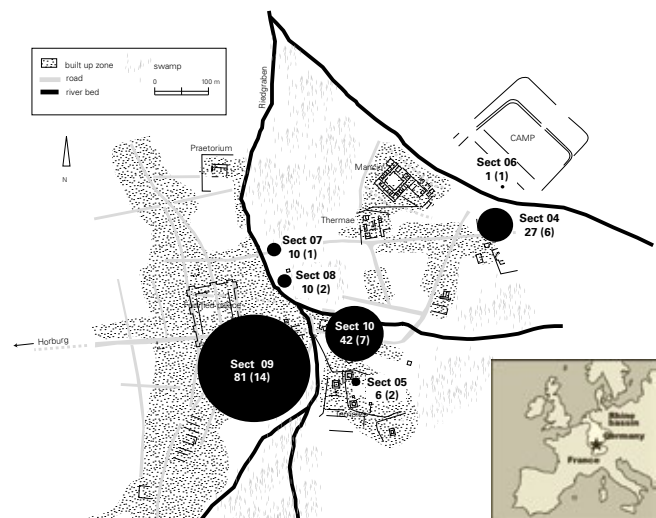


Fig. 1

The location of seven sectors providing wood and the distribution of 177 series of oaks dated and regrouped in 33 dendro-archaeological features.

Dating of archaeological woods

Tree-ring widths were measured at least twice in each archaeological sample with a Lintab and TSAP system (Rinn, 1989). The chronology development was performed using the *Sylphe* program (Meignier, © GNU-GPL 2001). Similarity between raw series was estimated by the coefficient of parallel variation (*Gleichläufigkeit*, GL/RW, Eckstein, 1969), and between detrended series by the Pearson correlation coefficient. Match decisions are first based on *t*-value computation as described in Baillie and Pilcher (1973), after standardisation of raw data in three ways, according to Lambert (2006) (*t*/iE), Munro (1984) (*t*/BP) and Hollstein (1980) (*t*/H). Secondly, a *z*-score transformation (Jansma, 1995) of the *Gleichläufigkeit* was taken into account. An acceptable visual agreement between graphical curves was verified.

The BK-ref177 chronology calculated, depending on the case, by averaging 177 individual raw or index series shows high correlation with differing regional references developed by various authors and labs using varying systems and methods, and spans the period 173 BC to 180 AD (Tab. 1). Regardless of the standardisation procedure, the highest correlation values are obtained with the master chronology nearest to the site: the Lorraine reference (W. Tegel, DendroNet, pers. comm.).

To assess the BK-ref177 chronology construction, individual series are checked with the aim of describing the common signal, variability characteristics and error risk on synchronisation. The correlation coefficient and *t*-value of each individual series with the master chronology, the member tested excepted, are computed by *C-Dendro* (Larsson, accessed 2010). Three *t*-values are compared: the *t*-value at the “chosen or tested” date, the highest and the next best, which can also be called the “first rejected” *t*-value. For the 177 series, the highest *t*-value rejected is 5.2, but the distribution shows a very high proportion of values between 3 and 3.5 (Fig. 2). The chosen *t*-value is higher than 5.2 for the 128 series the most directly linked to the common signal. The synchronisation with the overall chronology is not significant for 17 individual series, which is to say approximately 10%. In these cases the date is not selected based on common signal and high *t*-values. Some “atypical” series need to be grouped before being synchronised with the whole population. Others are dated with the help of archaeological arguments, for example due to anatomical anomalies or a poor number of rings.

Dendro-archaeological features

After exchange of dendrochronological and archaeological information, each series is associated with a “dendro-archaeological feature” representing the homogenous chronological state of a

coherent archaeological structure from a technological and/or topographical point of view. At the scale of the site, 33 different dendro-archaeological features have been identified, which can be grouped in four kinds of structures: 1) alignments of stakes used to stabilise quay-side roads and banks similar to those which have just been presented; 2) the construction of a pool and a fountain, along with the woods used in their repair and modification; 3) geographically individual structures for which function remains uncertain, and finally 4) isolated posts.

These architectural structures are almost exclusively in oak, the use of which necessitates no specific technological provision. For a carefully designed structure such as the pool, the woods are not really assembled but simply placed one on top of the other. The cutting of logs conforms to what has been observed in other sites from the same era. This is mainly the splitting and squaring of posts or the radial cleaving of planks.

The use of fir was restricted to the bottom of the fountain and also to a structure whose function is unknown. This species does not grow near the site. Supplying the site in fir thus implies a specific route coming from mountainous zones. In contrast, the 177 series of oak ring widths spread over two centuries are a good representation of the “*chêne bon à bâtir*” (“good building oak”) used in the settlement. It is a wood considered as timber logs based on its characteristics (species and dimensions), but whose specificity remains weak, therefore probably implying short and numerous supply routes.

Method and characteristics of archaeological woods

Estimation of the age of the trees used

The definition of dendro-archaeological features allows attribution of a single felling date to a given group of wood samples. The number of measured rings from eroded wood samples is then completed up to the most recent date for the group. If the date is within a given range – since no sample for a dendro-archaeological feature is complete all the way to the bark –, the estimation of the age also contains both a minimal and a maximal value.

Several techniques have been compared to estimate innermost rings destroyed: 1) direct observation with the radii materialized on a transparency, 2) techniques based on photographs, or 3) drawings of a cross section on a scale of 1:1. The number of rings represented by the missing distance is calculated on the basis of the average growth rate of the first five rings present (in mm per year). Several methods were also tested for this project. It appears quite probable that the greater the quantity of lost wood, the greater the error in the estimation of the age of a tree. The publication of a work undertaken on complete cross sections

Reference name	Site location	Laboratory (author) or (publication)	Overlap	Date	Standardised index			Raw date	
					t/BP	T/H	T/E	GL/RD	z/RD
Lorraine-Classic4	France, Lorraine	DendroNet (Tegel)	353	180	14.5	14.2	14.6	72.5	8.3
WestDeutschland	western Germany	Trèves Museum (Hollstein 1980)	351	180	13.6	12.7	-	72.6	8.5
France-ClassicOaks	France, large northern area	LCE-Besançon (Durost 2005)	353	180	12.0	10.0	13.8	72.4	8.4
Frache-Comté	France, Franche-Comté	LCEandt Cedre Besançon (Perrault)	353	180	11.8	9.1	11.9	70.6	7.7
Neuchâtel-Rom1990	western Switzerland	Laténium (Gassmann)	353	180	10.2	8.9	8.9	66.6	6.1
Wurttt200	Germany, Württemberg	Univ. Hohenheim (Becker <i>et al.</i> , 1985)	353	180	10.1	10.7	10.0	69.0	7.1
SüdDeutschland	southern Germany	Univ. Hohenheim (Becker, 1993)	351	180	10.0	10.6	-	68.0	6.7
NEF3	northeastern France	DendroNet (Tegel)	353	180	9.9	10.9	10.8	67.1	6.4
Bourgogne	France, Burgundy	LCE-Besançon (Lambert)	353	180	9.4	6.0	9.9	63.2	5.0
Baden-Württemberg	Germany, Württemberg	LDA Hemmenhofen (Billamboz)	274	180	8.4	10.3	-	68.5	6.1

t: t-value / BP: Baillie-Pilcher (1973) / H: Hollstein (1980) / IE: Lambert (2006) / GL: % of parallel variation / z: z-score

Table 1

Cross-dating results between the Oedenburg site chronology and reference chronologies.

from living oaks in Spain (Rozas, 2003) shows that for this group of trees the error in the method that we used at Biesheim is approximately 20%, but may be more than 40% in unfavourable cases. We eliminated the most critical ones: sub-parallel radii, several points of convergence, widely differing averages in the level of growth, etc. However, our decision was to include the greatest number of woods, with an uncertainty that could be tested, so as to arrive at an estimation of age based on a sample tree population as broad as possible. The estimation of the age for the 42 woods with their pith preserved is a better one, but it is not certain that it furnishes a better perception of the age of the population since to retain only this criterion is to exclude the greatest diameters, of which only one exterior was available to us.

In addition, whether the pith is present or not, the analysed cross section comes from the part of the archaeological object most likely to provide the greatest number of rings. The height of the transformed tree at which the cross section is found is variable and cannot be estimated. The estimation of the proposed age is therefore minimal if the sampled section comes from a high point in the trunk or even from thick branches.

A dendro-typology to highlight local “growth settings” and for a definition of “dendrological *terroir*”¹

The similarity between the series of ring widths is measured by the correlation coefficient after their standardisation in accordance with the procedure presented by Lambert (2006). The

correlation values are calculated between all pairs of samples. They are grouped together in a squared matrix having the same entries of lines and columns. The matrix is ordered in function of dendro-archaeological features. If the curves show a particular resemblance which can be observed graphically (Fig. 3), then the correlation coefficient is of the order of 0.8. We deduced that the woods in use came from the same tree. The hypothesis is confronted with the observation of how the wood was cut, since it is more likely that two cleaved planks would come from the same tree than would two boxed heart posts.

The matrix, ordered by dendro-archaeological features, makes it possible to calculate mean correlation coefficients based on series from the same feature and between different features. This calculation excludes coefficients that are attributed to series from the same tree. In the example presented (Fig. 3), the average correlation between seven series from an alignment of posts found in a river bank rises to 0.58. Likewise, it rises to 0.45 between the series of woods from a footbridge that was used to cross a channel. The average correlation between these two groups of series is weaker, 0.32. These coefficients are overall lower than those obtained between series from the same tree, evidence of trees subjected to similar conditions of growth, under the same local influences.

A stele with an anthropomorphic figure carved on a tree whose felling date is near to these dendro-archaeological features presents a growth curve with further differences (coefficients of 0.3 and less). Archaeological arguments indicate that the stele, discovered to be of re-used wood, is not a part of the architectural projects. The coefficients indicate a different setting.

In this approach, the variation between series – or, graphically, between “growth patterns” – of trees is compared to archaeological observations so as to construct a dendro-typology. However, trees are analysed according to their dating. Yet this

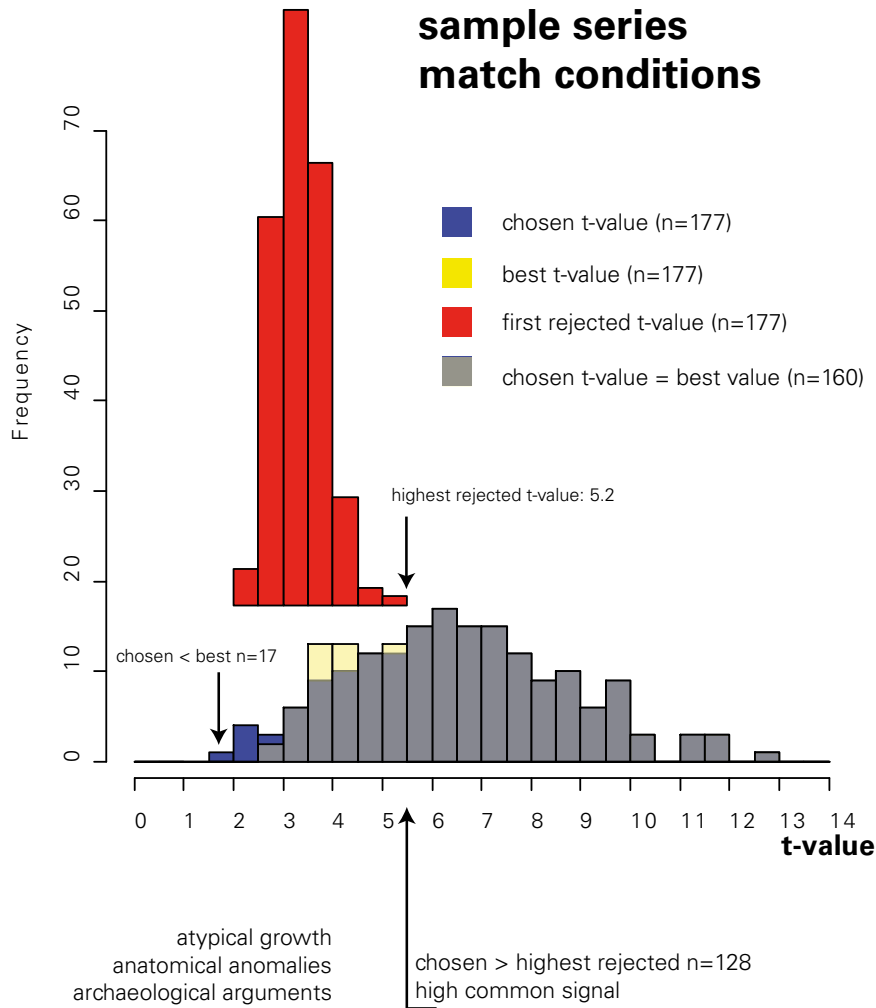
dating relies on the existence of a signal common to the series, which finds its source in regional ecological factors, common to the zone of origin of the woods, such as climate. The correlation between the series is therefore globally positive. Each tree is subjected to these global influences differently, especially the degree of intervention of local factors. The average correlation of a series with all the others is all the higher if the series shares in these global influences. Local influences thus become clearer in expressing the correlation between each pair in terms of the departure from the average calculated for a series with all the other series analysed (the average of a column or of a line of the matrix). The result is presented graphically for the example previously detailed (Fig. 3). A link is brought into evidence between dendro-archaeological features and local growth settings.

We propose to call the different local growth settings a calculation can bring out “dendrological *terroir*” because “good building oak” can be understood as a particular forest product and local growth influences associate abiotic and biotic factors including anthropics factors or practices, like different wood products harvest cycles but also non-timber products, pannage, hunting...

A test can be undertaken through application to a present-day forest group submitted to a homogeneous climate. Near Angers (Maine-et-Loire, France), 61 oaks spread over six sampling plots in two forested areas were cored. The trees whose growth presented the best correlations corresponded to the terrain with specific edaphic conditions for pH and water supply as highlighted by a particular vegetation (Fig. 4). To these pedologic conditions, it might be necessary to add the conditions of the competition between individuals rendered homogeneous by silviculture for each plot.² In this example, the “dendrological *terroirs*” are statistical representations which correspond to the sampling localities since they are arranged by ecological

1. The “*terroir*” is defined as a delimited territory identified by a specific product, resulting from physical conditions and cultural practices of a human community. The concept of “*terroir*” is clearly justified here: at Oedenburg, the product is “*chêne bon à bâtir*” or “good building oak” (oak suitable for building) discussed above. The physical conditions of the soil, altitude, etc., “potentially” allow its production, and model the growth of oaks in interaction with the climate. Cultural practices reveal, limit, orient and even destroy the natural potential. Simple exploitation, with an underlying concept of resource management, is already in itself a practice, but during the Gallo-Roman period, one must propose hypotheses that exploitations were based on collective decisions and were followed by a “*mise en défens*” period (maintenance period) in order to protect oak renewal.

2. These observations justify the utilisation of the concept of “*terroir*” for populations of modern trees because silvicultural practices guide in a structured way the “natural” population potential toward economic objectives. By extension, we use this concept in the past for demonstrate the interaction of the natural potential with silvicultural practices linked to the needs and the economy of societies for forest products. Specialisation toward particular productions from units of the territory in balance with physical conditions is knowledge of societies shown for example for the Neolithic (Pétrequin, 1992). Even if, unlike cultures, the forest most often keeps the “natural” possibility of developing, once a society exists, silvicultural practices model this potential.



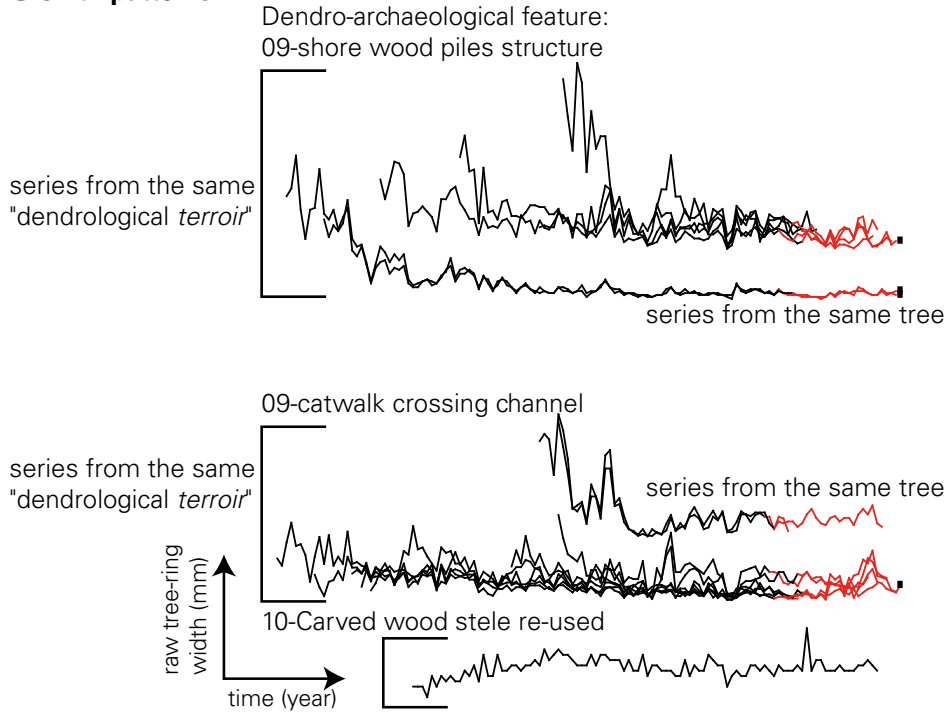
	chosen t-values					best t-values					first rejected t-values				
	Years	set	lap	CorrC	TTest	set	lap	CorrC	TTest	Ref to	set	lap	CorrC	TTest	
BK00.06.2	83	28	80	0,55	5,9	28	80	0,55	5,9	180	6	80	0,27	2,5	158
BK01.04.38.1.1.39.1	61	53	58	0,59	5,4	53	58	0,59	5,4	180	121	30	0,47	2,8	248
BK01.04.38.11.1	64	35	61	0,41	3,4	35	61	0,41	3,4	180	81	61	0,36	3,0	226
BK01.04.38.11.11	71	37	68	0,27	2,3	83*	68	0,36	3,2	226*	-13	54	0,31	2,4	130 -- !! --
BK01.04.38.11.13	50	73	47	0,66	5,9	73	47	0,66	5,9	180	51	47	0,42	3,1	158
BK01.04.38.11.14	56	98	46	0,71	6,7	98	46	0,71	6,7	180	40	53	0,46	3,7	122
... (n=177)															

C-Dendro <http://www.cybis.se/forfun/dendro>

Fig. 2

Frequency histogram of “chosen t-values,” “best t-values” and “first rejected t-values” calculated between sample series and average chronology, excepted member tested.

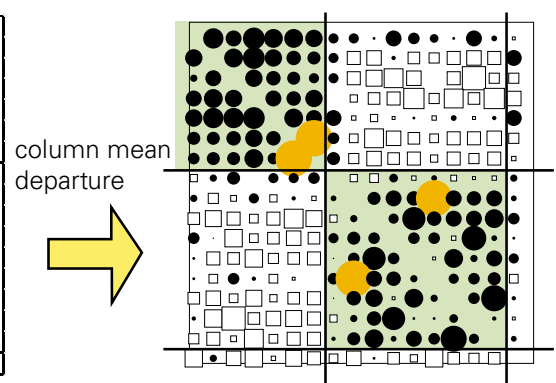
Growth patterns



Corresponding square matrix of correlation coefficient

piles structure	BK03.09.207	0,68	0,51	0,65	0,68	0,59	0,57	0,44	0,51	0,37	0,56	0,48	0,48	0,39	0,49	0,41	0,26	
	BK03.09.203	0,68		0,57	0,63	0,67	0,52	0,51	0,44	0,32	0,22	0,40	0,29	0,34	0,26	0,18	0,27	0,44
	BK03.09.802	0,51	0,57		0,54	0,61	0,48	0,45	0,44	0,31	0,21	0,14	0,24	0,42	0,27	-0,04	0,31	0,20
	BK03.09.800	0,65	0,63	0,54		0,63	0,52	0,58	0,39	0,27	0,27	0,11	0,34	0,14	0,24	0,10	0,13	
	BK03.09.206	0,68	0,67	0,61	0,63		0,59	0,56	0,53	0,42	0,34	0,37	0,38	0,40	0,41	0,32	0,40	0,44
catwalk	BK03.09.208	0,59	0,52	0,48	0,52	0,59	0,82	0,45	0,38	0,12	0,23	0,27	0,36	0,27	0,21	0,25	0,20	
	BK03.09.209	0,57	0,51	0,45	0,58	0,5	0,82	0,47	0,36	0,22	0,28	0,25	0,38	0,26	0,25	0,26	0,25	
	BK03.09.221	0,44	0,44	0,44	0,53	0,47	0,39	0,32	0,43	0,36	0,45	0,36	0,32	0,37	0,31			
	BK03.09.224	0,51	0,32	0,31	0,39	0,42	0,38	0,36	0,39	0,48	0,54	0,52	0,87	0,57	0,47	0,55	0,30	
	BK03.09.156	0,37	0,22	0,21	0,27	0,34	0,12	0,22	0,32	0,48		0,46	0,71	0,56	0,57	0,51	0,62	0,37
stele	BK03.09.199	0,56	0,40	0,14	0,27	0,37	0,23	0,28	0,43	0,54	0,46		0,47	0,52	0,37	0,73	0,41	0,28
	BK03.09.126	0,48	0,29	0,24	0,11	0,38	0,27	0,25	0,36	0,71	0,47		0,41	0,62	0,37	0,55	0,34	
	BK03.09.198	0,48	0,34	0,42	0,34	0,40	0,36	0,38	0,45	0,87	0,56	0,52	0,41		0,46	0,43	0,51	0,22
	BK03.09.125	0,39	0,26	0,27	0,14	0,41	0,27	0,26	0,36	0,57	0,37	0,62	0,46		0,43	0,83	0,29	
	BK03.09.197	0,49	0,18	-0,04	0,24	0,32	0,21	0,25	0,32	0,47	0,51	0,73	0,37	0,43	0,43		0,40	0,26
BK03.09.104	0,41	0,27	0,31	0,10	0,40	0,25	0,26	0,37	0,55	0,62	0,41	0,55	0,51	0,83	0,40		0,30	
carved wood	0,26	0,44	0,20	0,13	0,44	0,20	0,25	0,31	0,30	0,37	0,28	0,34	0,22	0,29	0,26	0,30		

Graphical presentation



Averaging by dendro-archaeological feature

	piles structure	catwalk	stele re-used
piles structure	0,58		
catwalk	0,32	0,45	
stele re-used	0,27	0,30	-

- coefficient < column average
- coefficient > column average
- series from the same tree
- series from the same "dendrological terroir"

Fig. 3

Method of classifying the similarity of growth series according to archaeological hypotheses with the goal of distinguishing between woods from the same "local settings" and the same individual tree. Admittedly, the series are all the more similar when the source factors of their ring-width variations are similar.

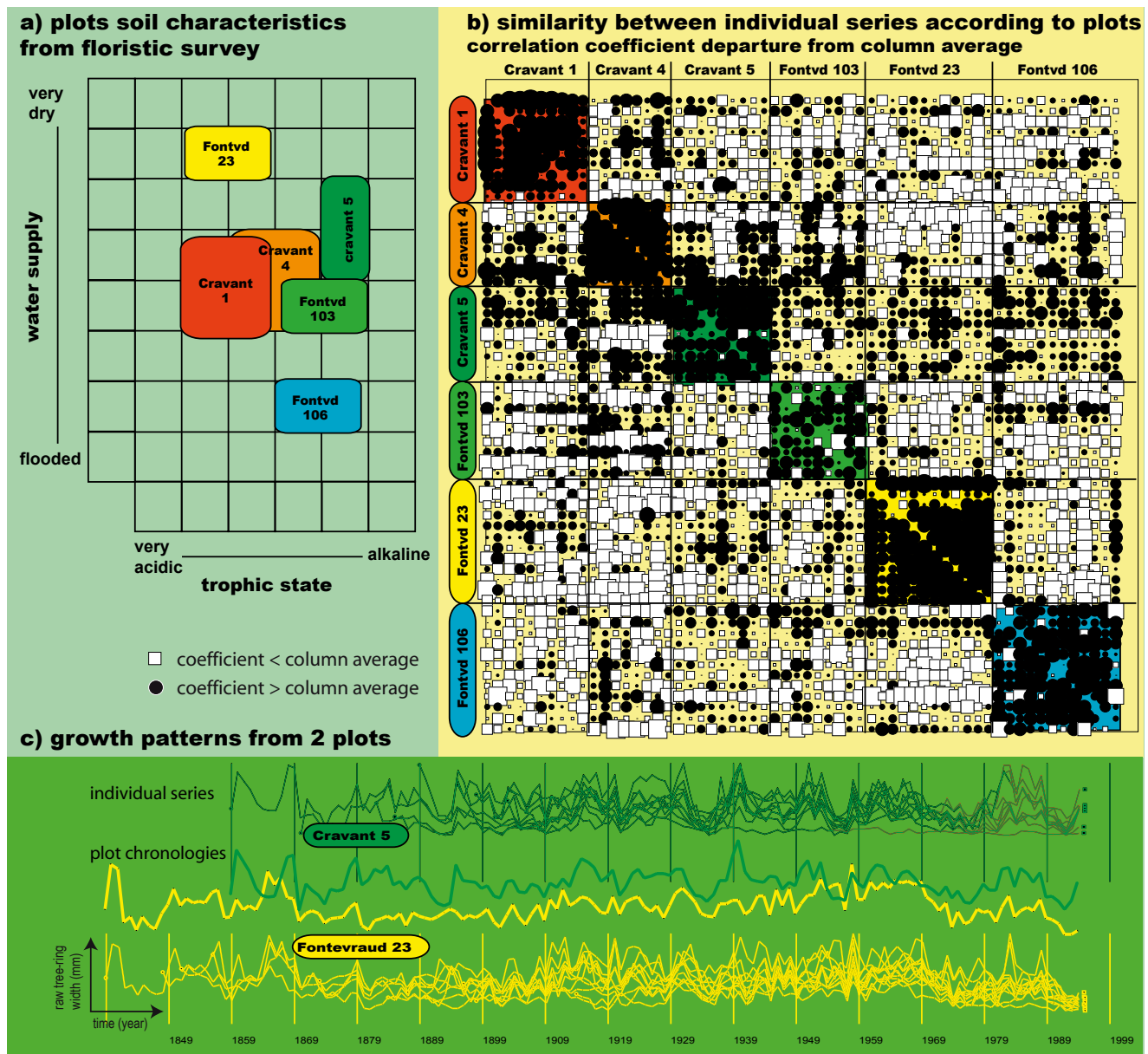


Fig. 4

Figure of the concept of “dendrological *terroir*” in the present-day forests of Fontevraud (Maine-et-Loire, France) and Cravant (Indre-et-Loire, France).

- A** The floral reading of all species allows characterisation of edaphic conditions of sampling plots synthesised by trophic and hydric levels.
- B** The squared matrix of the similarity between series of widths measured on each individual is ordered according to plot.
- C** Growth patterns show greater similarity within the plots than between them. Within the homogeneous climatic whole, the average gap by column brings to light the “dendrological *terroir*” in relation to local influences.

diversity. In contrast, these zones more generally do not have a geographical reality but rather a functional one, linked to the variability of ecological factors. For example, if the tree harvest does not include sufficient ecological diversity, the influence on growth will be weak. If two geographically distinct groups have a comparable functioning, they will not be discriminated (for example, from the bottom of a small valley).

The evolution of growth in function of current age: “age trend”

All other considerations notwithstanding, an oak forms narrower rings as it ages. With age, an oak tends toward maximal dimensions, in both height and diameter. These *maxima* are under the influence of different constraints. Some of them are internal: the potential of the species and of the individual. Others are connected to the overall environment, such as climate. In a given regional zone, the quality of the location, mainly the soil, defines a potential volume. Competition between individuals and species, that is to say between neighbours of the same or different species, has greater influence on the form of the oaks and thus on the distribution of the potential volume between the crown and the trunk, in diameter and height. The type of incidence of light, indispensable for photosynthesis, conditions the form of the leaf surface area (Bary-Lenger and Nebout, 1993). A tree isolated or growing within a hedge receives light from all directions. It is subjected to only very weak competition. Inversely, a tree in a dense and tall forest receives light only on its canopy. It gains access to light by growing higher than its neighbours. Its trunk is longer and with a diameter smaller than that of an isolated tree. The study of living populations of different structures makes it possible to examine the evolution of ring width in function of age: “the age trend”, within the constraints of very different conditions of competition (Fig. 5). In the hedges sampled, annual production diminishes slightly with age, from 3 mm to just more than 2 mm toward 150 years. The Franc-Comtois forests analysed for this study were managed as coppices-with-standards during the 19th century and through the first quarter or even the first half of the 20th century. Under this type of management, the density of the dominant trees, the standards, remains low. The crowns are rarely in contact. The coppice is exploited in the understory, with stump sprouts harvested at each rotation, and the future dominant trees chosen mainly from seed trees (Lanier *et al.*, 1994). Ring-width development depending on age first shows a decline from 2.5 mm per year to 2 mm and then an increase, until around the age of 30 years, again to around 2.5 mm and finally a decrease to 1.5 mm at about 150 years. The decline during the first 30 years is related to competition from more

vigorous stump sprouts from seed trees (Badeau, 1995). In the forests studied by Becker *et al.* (1994) in Lorraine, the conversion from coppice-with-standards to high forest management took place during the 20th century. The different densities observed are greater than in coppices-with-standards: the oaks are in regular contact. Ring width declines from 2 mm to 1.25 mm at around 100 years, and then to 1 mm at around 200 years. The analysed forests thus show a staging in their “age trend” curves as a function of population density, which is to say dependent on the constraints imposed on tree diameter by competition. Insofar as competition is not the only factor influencing this curve, the method does not pretend to find in the past any of the present-day models that have been developed in much more standardised silvicultural conditions. Long-term changes in the environment, climatic changes for example, conceivably act upon productivity according to age. However, the structures of former populations may be described in comparison to the characteristics of present-day forests.

The logging of forests

Tree age at the logging site

The growth of 177 dated oaks covers the period between 173 BC and 180 AD. They are grouped in 33 dendro-archaeological features “correctly” spread over approximately 200 years (Fig. 6). These vestiges are rare witnesses, relics of the volume of wood brought out of the forests. Of this volume, it is likely that “good building oak” constitutes only a small part of forest products in comparison to, for example, firewood. Yet the wood samples that we have obtained are recordings of the structure of the populations of which they were a part, via the influences on growth by local ecological factors such as population density, and by their characteristics such as age at the time of harvest. The number of trees studied is thus in no case quantitatively representative of forests, but the validity of the sampling comes from the fact that each one describes a local forest situation at the moment of each of the 33 fellings.

Figure 6 shows that between the first harvests, shortly before 10 AD, and those of 120 or 130 AD, the trees chosen are increasingly older. In fact, though the exploitation dates advance in time, the contributing populations are all regenerated at similar dates centred on 100 BC, between 130 and 70 BC. It was not until 145 AD that younger oaks began to be used, appearing at the moment of the fellings of the beginning of the first century AD. Within the period of this study, regeneration thus does not follow a curve parallel to exploitation since a break appears at the beginning of the fellings of 145 AD.

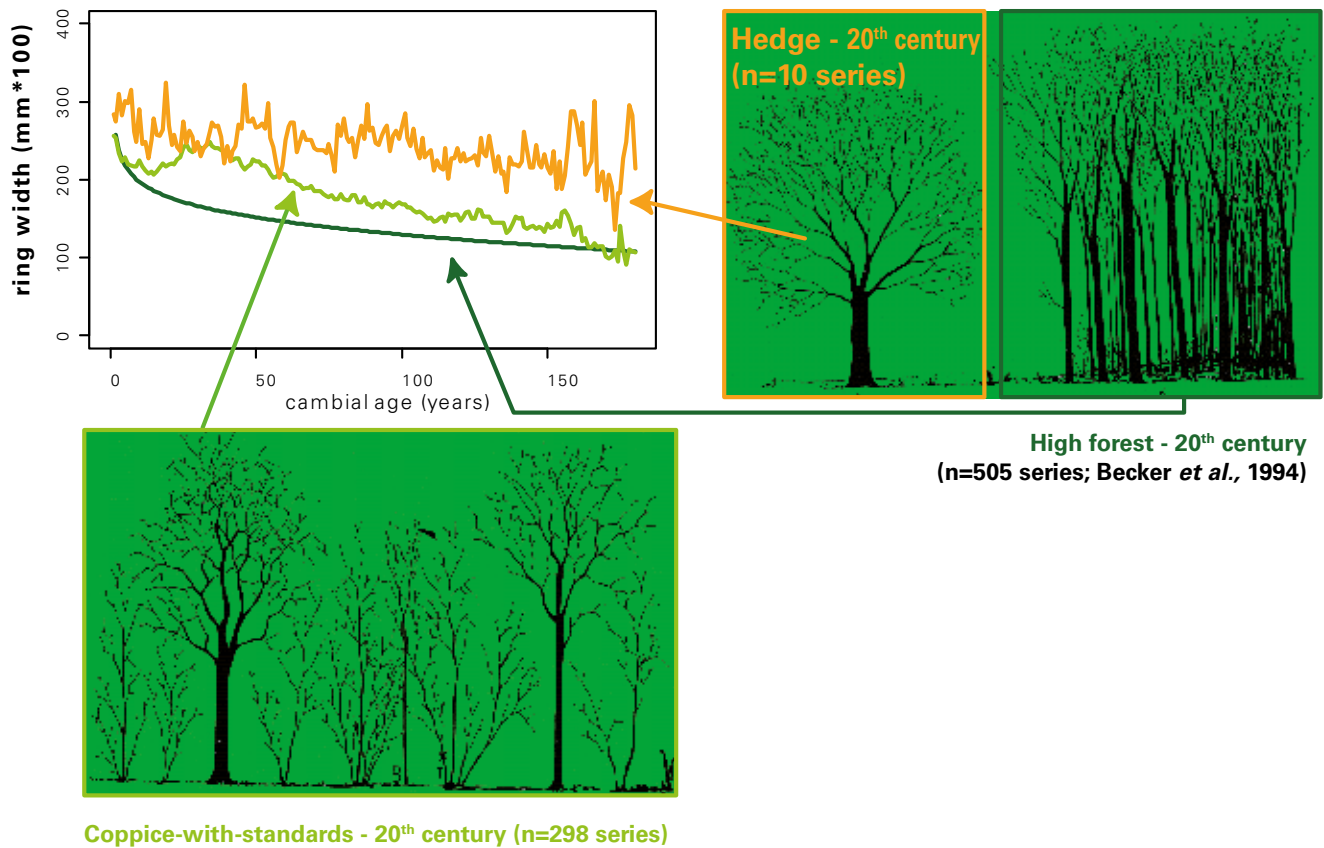


Fig. 5

“Age trends” observed in populations where silvicultural practices lead to widely differing densities of individual trees. The hedge trees in Oussières (Jura, France; analysis by the Laboratoire Chrono-Environment) are remarkable. Wide variations are observable for one trend because the number of samples is limited to only ten. The curve for high forests is a model adjusted to the data of 505 trees from the forests of Amance and Champenoux (Meurthe-et-Moselle, France; Becker *et al.*, 1994). The curve for coppices-with-standards is the average width of 298 trees from the Forest of Chau (Jura, France) and of several woodlands near Lure (Haute Saône, France; analysis by the Laboratoire Chrono-Environment).

The same observations may be made from another presentation of data which takes into account the error of age estimation (Fig. 7). Whatever the date, the grouping of points indicates that the ages of the trees are varied. Either the populations are indeed composed of varied age classes, or the samples were taken from a wide variety of heights on the tree. During the course of the first century AD, the trees are increasingly older

when logged. They are first harvested at an average age of 100–120 years, and then towards 180–200 years. Beginning in 120–130 AD, the number of rings decreases more rapidly than it increases and tends toward approximately 100.

The minimal and maximal estimations of age take into account errors on the convergence of the radii in the centre of the log and on the dating of dendro-archaeological features. These

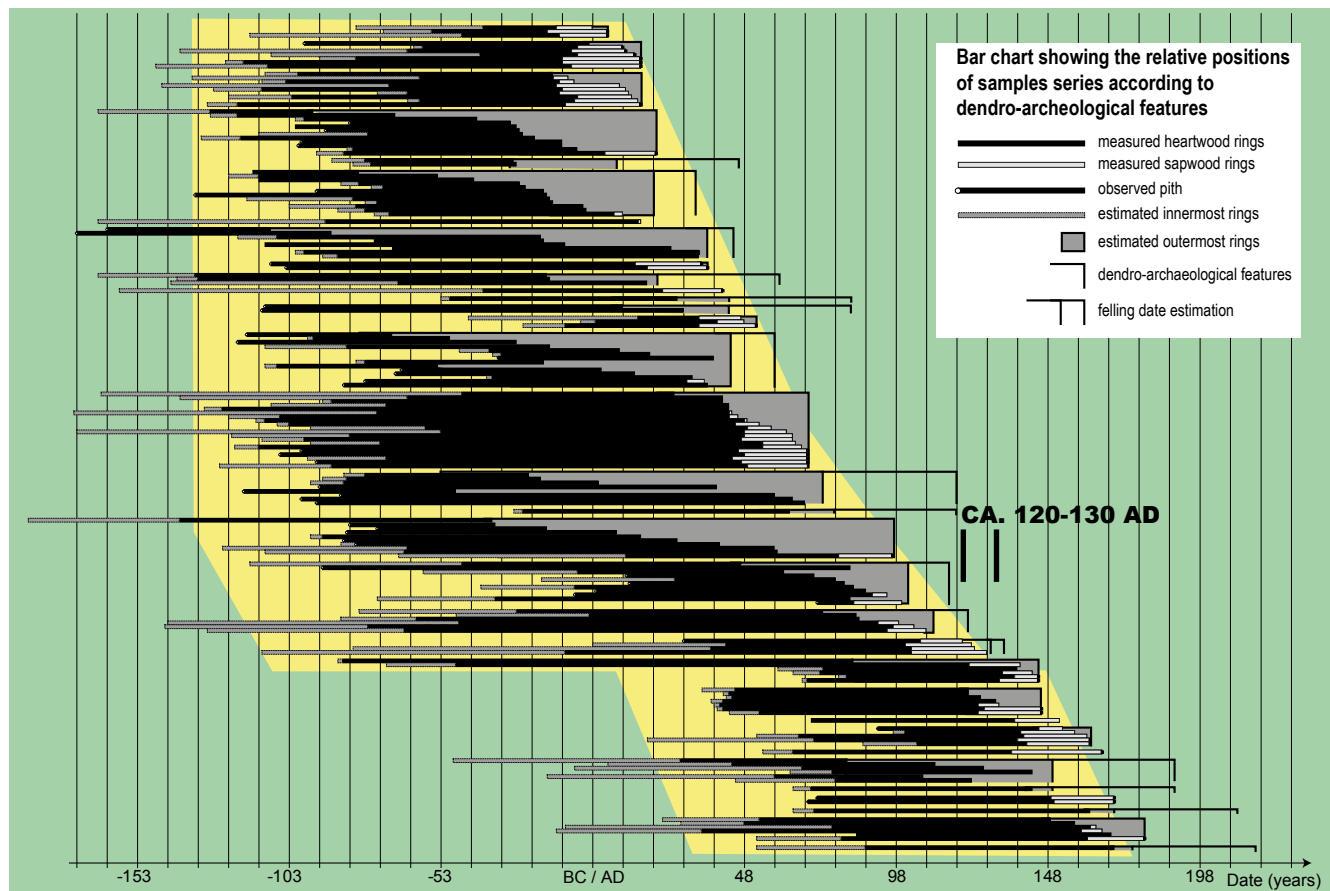


Fig. 6

Chronology of forest exploitation in terms of dendro-archaeological features.

estimations lead to the same pattern. Errors are thus spread out without contradicting the interpretation. It can nevertheless be noted that the maximal estimation leads to an increase in the trend toward 200 AD. It is not significant, but it indicates an overestimation of felling date. In fact, in a large population of oaks, it is more frequent for the number of sapwood rings to approach the average (21) than the maximum. These trees were more likely harvested toward 180 AD than after 200 AD.

Tree age is only slightly or not at all perceptible in a forest and is not a conscious criterion at the moment of cutting. Selection is mainly governed by the need for a minimal diameter and height that conform to the architectural project. The age at the time of exploitation is thus a consequence of productivity, which is to say the time necessary to attain the desired diameter and height. The age variations which have been described are closely

connected with the structure of the tree population since, over the same period, the estimation of the diameter of the harvested logs shows no evolution (Fig. 7). The changes in architectural choice, notably toward 120 to 130 AD, were not sufficient to influence the harvest. During the first two centuries AD, oaks were exploited, with few exceptions, with a radius between 10 and 30 cm (20 to 60 cm in diameter under the bark). Archaeological observations indicate that they are used in structures necessitating neither a specific selection of woods, nor a sophisticated technology. This constitutes the characteristic of what we have called “good building oak” which, among timber woods, may be comparable to the “*bois à maisonner*” (house timber) cited in the medieval sources of the Duchy of Burgundy (Beck, 2007).

In the first phase, increasingly older woods were used, which indicates a use of reserves. In fact, though the logging was entirely

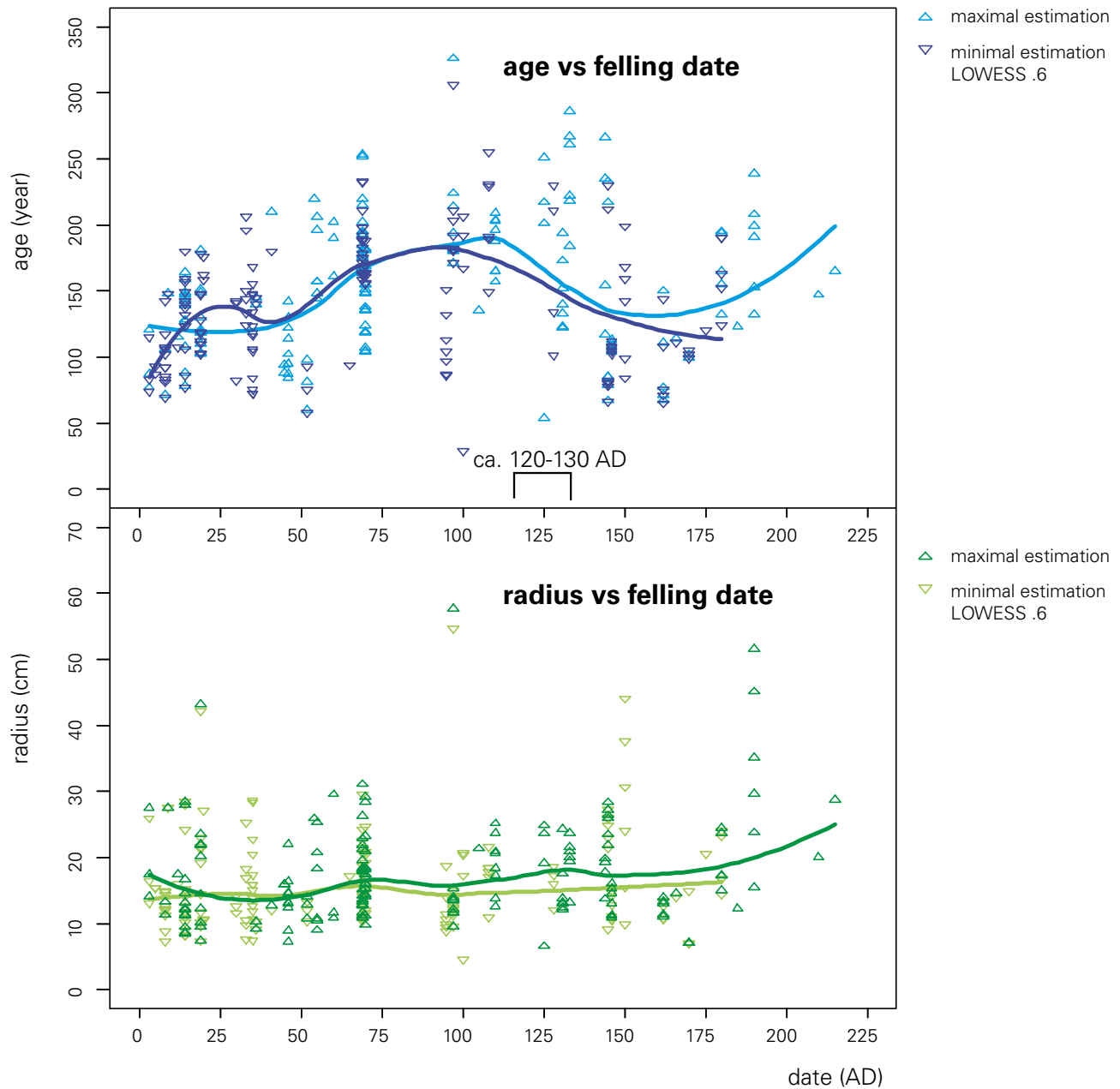


Fig. 7

Evolution of both tree age and radius as a function of felling dates. Minimal and maximal estimation calculated according to outermost and innermost rings and felling date estimations (LOWESS = locally weighted scatterplot smoothing).

compensated by regeneration, exploitation may have taken place at a constant age. Regeneration did indeed take place and was included in the harvests. This is shown by a greater dispersal of the point grouping whereas the average age increases. From around 10 AD to 120–130 AD, the age groups that were exploited

showed greater and greater variety. This means that removal went beyond the capacity for regeneration, with less productive trees, increasingly older, being harvested. After 120–130 AD, the average age declines, with younger trees being cut down. Indeed, the choices show two distinct age groups (Fig. 7). Reserve trees

as old as 250 years are found with much younger trees whose growth is rapid. The former show the use of the last trees regenerated toward 100 BC, and the latter those produced in an environment transformed by the increased rate of exploitation.

Logging

The 19 dendro-archaeological features which include at least four different woods have made it possible to organise the matrix of comparisons of different series. The woods included in a single feature have more similar growths than that found for differing features.

In the 19 cases, the average correlation between the series of the same feature is greater than that calculated between different features. The difference is the highest for structures 2, 3, 9, 13 and 16 (Fig. 8), corresponding to successive facilities established at Riedgraben channel. The trees used in a structure come from a “dendrological *terroir*”. It is therefore likely that the logging took place in the form of fellings that opened up a woodland zone and not with the selection of isolated trees.

The results show broad variability, greater than that observed in a test on present-day forests (*ut supra*). Certain groups of features present growths with more similarity than is found between study plots. The reality of “dendrological *terroirs*” is functional. The results show then that the area of fellings was rather limited and thus the specificity of local factors shows up in the growth. However, at the same time different fellings do not necessarily cross an ecological gradient that is as well-defined as in the example of present-day forests.

Generally, a link between archaeological structures and a harvest of timber woods becomes evident, via their growth similarities, and, in four highly favourable cases, by the concordance of felling seasons when several samples have their cambial zone preserved. It therefore appears that, even if the facilities in question did not necessitate sophisticated technology or specific woods, their very construction demanded that a decision be made to log a zone of forest land. A link exists between the architectural project and the felling. If the oaks had been harvested regularly, independently of the constructions, for commercial reasons or a large clearing for examples, it is likely that the woods used together in an archaeological project would have been cut in different seasons and come from different “dendrological *terroirs*”.

A forest logged yet remaining relatively dense

The development of ring width as a function of tree age is traced for the entire group of woods for the site (Fig. 9). It shows that during the juvenile phase, the rings are of highly varied widths. From an average of 2.3 mm, they often grow to 3 mm, and more

rarely to 4 mm. This phase of heavy growth is followed by a rapid decline toward an average of 1 mm at age 50. After 50, the decrease is clearly much less rapid. The average width is 0.7 mm at age 100. Production during the juvenile phase is, on average, comparable to that of present-day forests, 2 mm, but the decrease is much less well-marked. Widths at age 50 are approximately 2.25 mm in a coppice-with-standards and 1.5 mm in the thickest high forests.

In present-day forests, as for those represented by the samples, logging cuts open up the population and thus allows significant juvenile growth. The forest state is temporarily destroyed in the goal of regenerating it.

To explain the differences, the first hypothesis is that in managed forests, light and regular clearing every 8 to 10 years in high forests, and heavier clearing every 20 to 30 years in coppices-with-standards, will lower the population density and maintain the production level. However, the curves designed for the study of present-day forests take the dominant trees of the population largely into account, whereas the Gallo-Roman exploitation had to be based on all forest strata. The relatively greater presence of dominated oaks, necessarily less productive, thus explains the lower rate of production observed.

The diameter attained by the tree at age 30 is an indication of its individual rate of productivity. Site conditions act upon its value, but in its juvenile phase, this rate is more dependent on the status of the tree within the population. For the group of archaeological samples, the strongest values allow us to isolate the samples from the trunks most likely to be dominant. Inversely, the weakest values will show the dominated trees, but also will indicate objects made of wood from the branches. This will take into account, at least partially, the fact that archaeological samples come from different heights in the tree and from trees of differing status.

Age-trend curves from the entire group of wood samples are thus arranged according to diameter at age 30, in three classes for which an average is calculated. After 15 years, all the analysed trees had a production rate inferior to that observed within present-day hedges (Fig. 10). Whatever the class of diameter at age 30, the loss in productivity is high. They do indeed come from forest populations. The storeying of the curves is still perceptible at age 50, but they are all lower than the production rates observed in high forests.

Globally, for the first two centuries AD, the forests logged to furnish the settlement with “good building oak” may have been denser at age 50 than a present-day high forest. Before this age, the clearing recommended by current silviculture was probably not practised in Gallo-Roman forests.

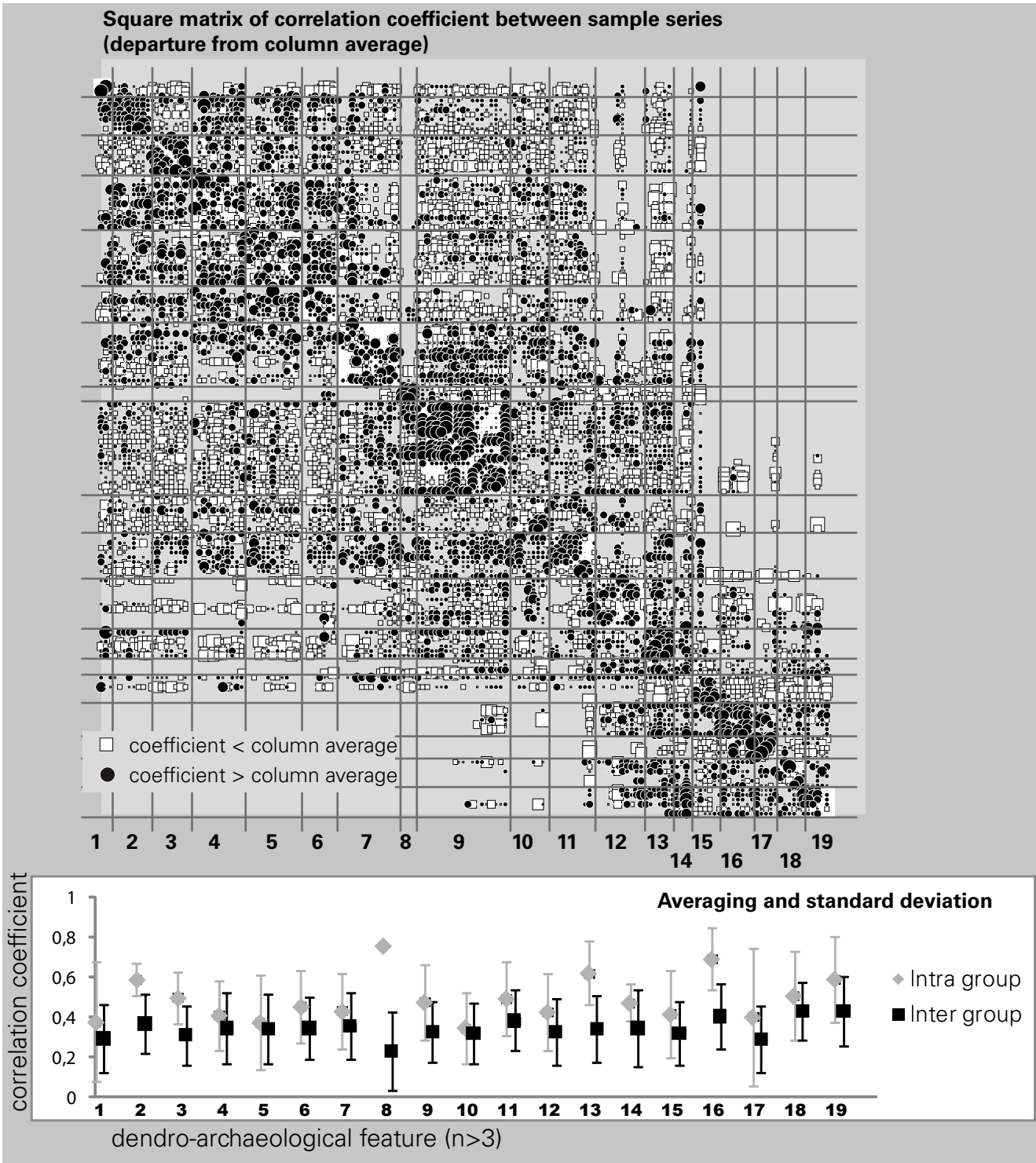


Fig. 8

Dendro-typological results for 19 dendro-archaeological features at Oedenburg.

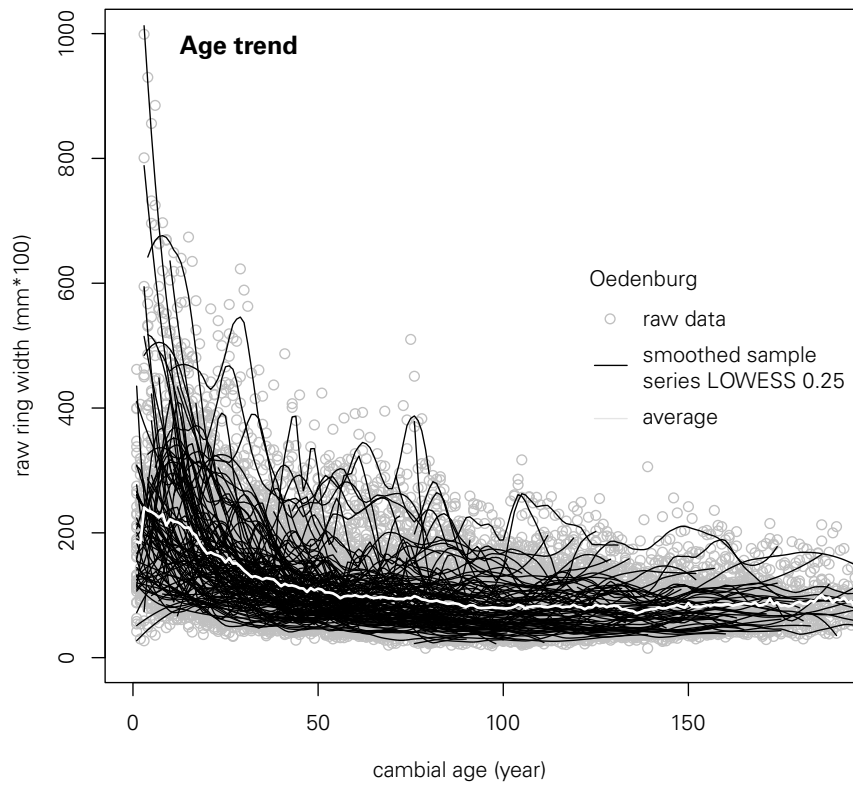


Fig. 9

Ring-width development in comparison to the age of the trees used at Oedenburg.

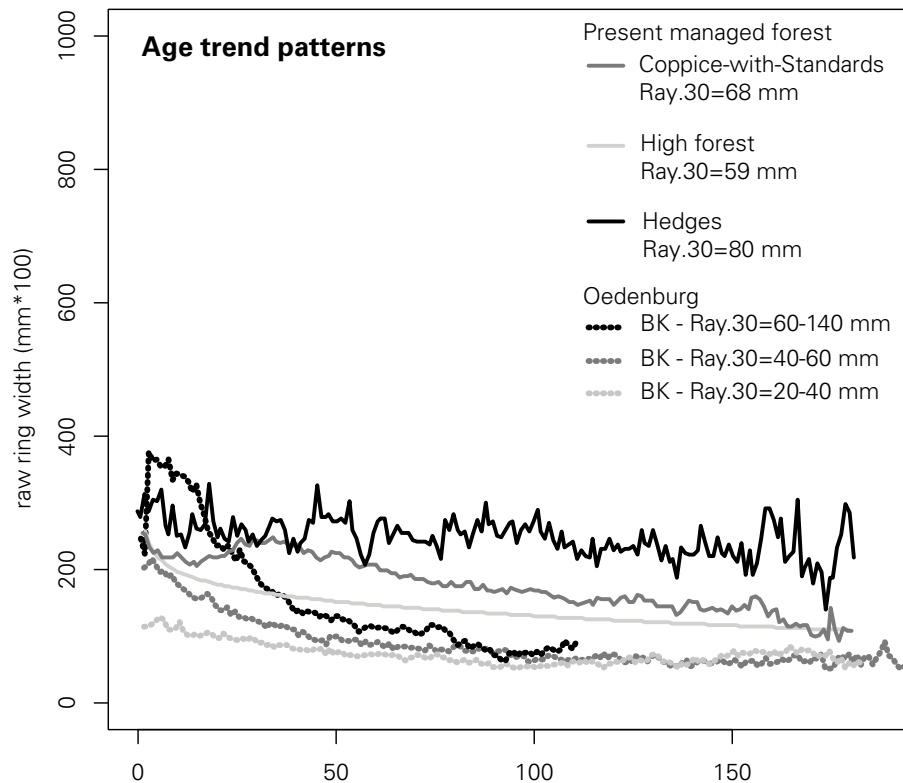


Fig. 10

Comparison of ring-width development as a function of aging at Oedenburg and in present managed forests of varying densities. Ray.30 gives the radius reached at 30 years.

Conclusion

In conclusion, over the course of the first two centuries AD, the succession of growth curves organised according to dendro-archaeological features makes it possible to identify three periods of logging for “good building oak” in the forests surrounding

the site of Oedenburg. From approximately 10 AD until about 55–65 AD, the oaks were felled at around an average age of 100–120 years. These trees, used at the beginning of the chronology from the Gallo-Roman settlement, came from populations regenerated between 130 and 70 BC. They show wide rings during their juvenile phase, a sign that they came from forests in which

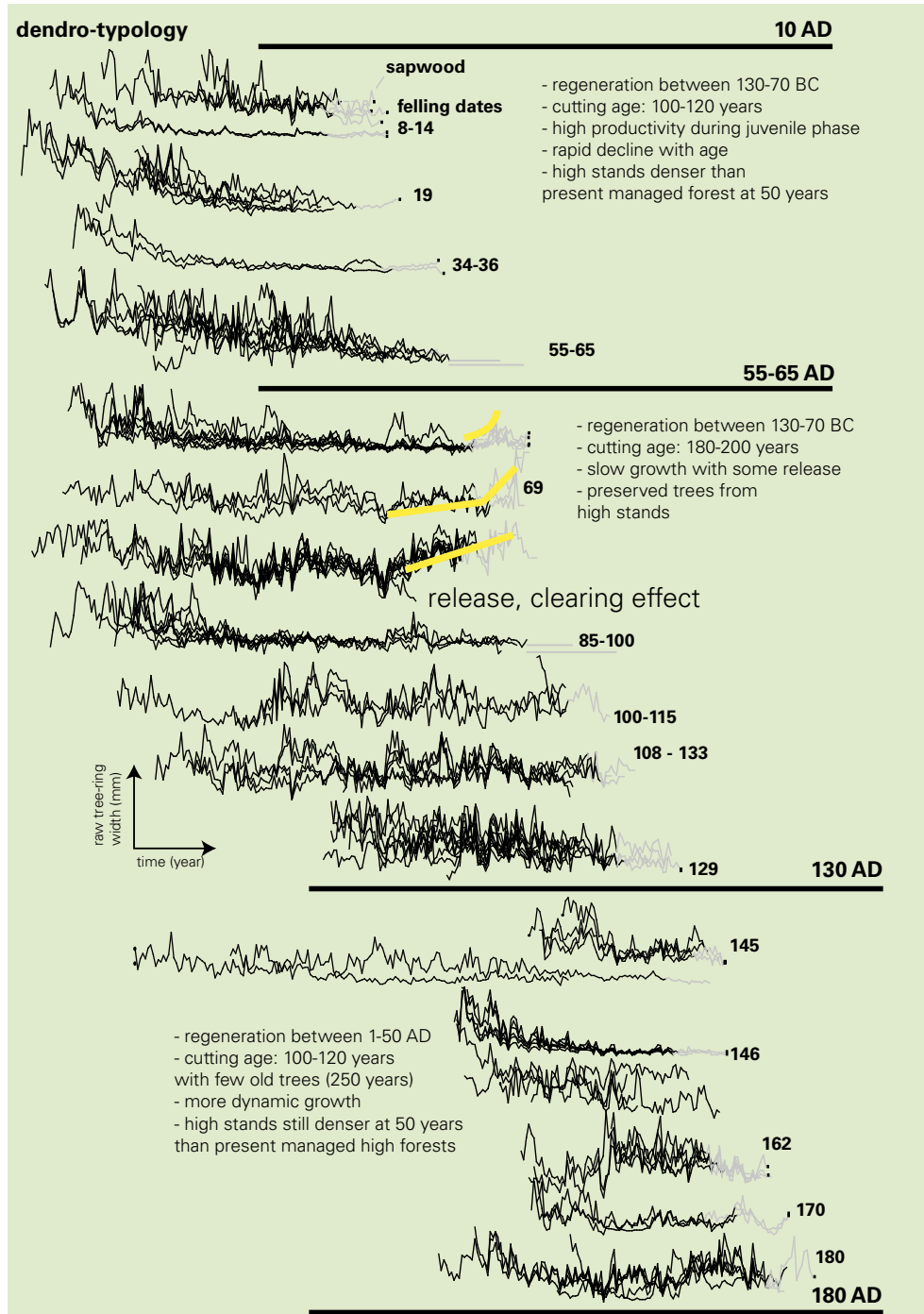


Fig. 11

Logging at Oedenburg based on the growth of oaks dated by dendrochronology.

previous logging had locally opened up the forest stands. In correspondence, archaeological evidence from this part of the Rhine valley (Jud and Kaenel, 2002) shows intensification of settlement during the period 150–70 BC of La Tène D1 followed by a decline just before the Gallic Wars (58–51 BC).

From 55–65 AD, some of the oaks still came from populations regenerated around 100 BC, such that the trees felled were older, 180 and sometimes 200 years old. Some of them present an increase in their growth which quite likely points to fellings in their environment (Fig. 11). However, all age classes satisfying the diameter requirement were harvested. Logging thus depended on regeneration and the mobilisation of reserves constituted especially by slow-production trees.

After 120–130 AD and more particularly beginning in 145, a few trees, aged approximately 250 years, still regenerated between 130 and 70 BC, were mixed with younger oaks from the environment transformed by logging during the first century AD.

Trees were harvested over that entire period. The similarity between the series of ring widths from woods of the same dendro-archaeological features shows that they come from the same “dendrological *terroir*”, linking architectural project and forest exploitation decision. The logging locally de-structured the forest state and allowed a regeneration which began by a growth at least as intense as that of present-day forests logged either as coppice-with-standards or as high forests. After this period, production falls. At age 50, it is clearly lower than that of a forest managed by periodic clearing. In the context in which reserves are used, fellings are in the interest of low-productivity trees. Unfortunately, the sampling does not permit a precise description of production variability as a function of age in the different situations which can be envisaged: the pre-settlement forest, during the growth period, and the consequences of the latter. Yet it can be retained that exploitation necessitated the mobilisation of reserves which seem dependent above all on a previous regeneration, thus showing an increase in the rate of logging and leading to a transformed environment perceptible at the end of the available chronology.

The dendrochronological approach to the Oedenburg corpus allows us to put forward additional interpretations of the dates of the structures of the exploited forests. However, the archaeological material presents constraints in comparison to living trees analysed by dendro-ecology. The position of the sample on the tree is one such constraint, but the most serious one is how to evaluate the representativity of the analysed wood samples. Indeed, living trees are selected to respond to questions defined according to the ecological variability of a given area, whether produced by abiotic factors such as soil or exposure or biotic

factors such as differences in population density. In contrast, dated trees imported onto the site from woodland areas cannot be localised and cover only a non-measurable part of their biotic or abiotic variability. The area of origin may be of variable size, information concerning the situations from which the oaks come is likely to be incomplete with respect to total variability, and the woods are “mixed” when used in objects or structures. It would therefore be dangerous to generalise, but the situation described here serves as a milestone for comparison with other sites, via the study of archaeological remains, leading toward a history of the exploitation of the resource of “good building wood”.

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