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ORIGINAL ARTICLE

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# Dendrochronology in suboptimal conditions: tree rings from medieval oak from Flanders (Belgium) as dating tools and archives of past forest management

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**Abstract** Throughout the Middle Ages forests in Flanders (northern Belgium) experienced a dramatic human influence. Forests were logged for wood supply and converted to arable land. The structure of the remaining forests was altered. This, combined with the tempering influence of the Atlantic climate, results in conditions that are suboptimal for dendrochronological research. Tree-ring series of *Quercus robur* and *Q. petraea* of timber from medieval archaeological sites are often short, show abrupt growth-rate variations and are complacent. The question arises whether tree-ring series of this type are potential records of past management and whether they could constitute the basis of a reference chronology for archaeological dating. During six archaeological excavations in and around the medieval town of Ypres, cross-sections were collected. The tree-ring series could be dated back to the 12th–14th centuries, using reference chronologies from surrounding regions. The growth pattern of the short sequences displays a high similarity to tree-ring series from modern coppice. For the first time, it has been confirmed that dendrochronological analysis in Flanders is possible and can provide valuable information on medieval forest use and structure.

**Keywords** Dendrochronology · Flanders · Quercus spp. · Expressed population signal · Coppice. Middle Ages

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## Introduction

Over the last 30 years, dendrochronology has become one of the standard dating techniques in archaeology, especially in Europe (e.g. Kuniholm 2001). The chance of successful dating depends strongly on a few, clear features. For example long sequences with high environmental sensitivity generally have a higher potential for dating purposes than short and complacent series. When analysing tree-ring series from archaeological wood in Flanders (northern Belgium), long and sensitive series are rare. There, a low number of tree rings depending on diameter and abrupt variations in growth rate due to anthropogenic influences, are common. This hampers the crossdating process, which is one of the basic steps in dendrochronological analysis. In addition, averaging raw tree-ring data with strong pulses of endogenous disturbances can bias the resulting chronology (Cook et al. 1990).

Even before the Roman era, forests in present-day Flanders were heavily exploited and degraded. During the Dark Ages (4th–7th centuries A.D.), a period of forest recovery started (Tack et al. 1993). Migrating Germanic tribes disrupted the organisation of local communities, exploiting the local forest resources. The conversion to arable land was interrupted and the forests could regenerate. From the 7th century onwards, this recovery phase was halted due to a growing need for staple food and fodder crops. This caused an increasing pressure on the remaining woodlands and forests. A demographic explosion during 10th–13th century accelerated the exploitation of forests for wood supply and deforestation for conversion to arable land. These processes resulted in the lowest forest cover ever in Flanders by the end of the 13th century.

Together with the progressing deforestation, the structure of the remaining forests was altered. Two management systems gradually became more popular in England, Northern France and Flanders: coppice and coppice-with-standards (Bechmann 1990; Vera 2000; Rackham 2003). The main goal of these interventions was to create a sustainable wood supply for construction and fuel, and fodder for pig breeding.

The combination of high anthropogenic pressure with the tempering influence of the Atlantic climate results in conditions that are considered as suboptimal for dendrochronological research. In this regional climate temperate deciduous forest is the climax vegetation, in which oaks (*Quercus robur* L. and *Q. petraea* (Matt.) Liebl.) occupy an important position. These oaks experience climate conditions favourable for growth, expressed in wide growth rings and ring-width series with a low sensitivity to climate.

In order to support the interpretation of archaeological findings, one of the main goals of a dendrochronological analysis is the exact dating of excavated wood specimens. The lack of reference chronologies composed of local tree-ring series from Flanders is a drawback in the application of dendrochronology as a dating tool. As a result, master chronologies from surrounding regions must be consulted.

For dating purposes in an archaeological context, it is important to report the exact felling date of wood specimens. This is only possible when all the sapwood rings are still present in a transverse section. When sapwood is absent, only a *terminus post quem* can be calculated (Eckstein et al. 1984; Baillie 1995). When part of the sapwood is preserved, the felling date is estimated using a mean number of sapwood rings. This mean number is considered dependent on two main factors: the age of the tree and its geographical location (Hollstein 1980; Hillam et al. 1987). Such standard sapwood estimates are available for different regions throughout Europe. Sapwood estimates for oak from Belgium most frequently rely on the age-dependent standards for Western Europe. A subdivision is made by 100 year age classes. For trees up to 100 years 16±5 is considered as the mean number of sapwood rings. This number is increased for a tree with an age between 100 and 200 years to 20±6. Trees older than 200 years are expected to have 26±8 sapwood rings (Hollstein 1980). All these estimates are based on the 68.3% confidence level and are derived from tree-ring series originating mainly from trees within primary forests. Since primary forests were obviously no longer present in medieval Flanders, the relevance of the sapwood estimates is questionable.

Extensive dendrochronological datasets can form the basis for a reconstruction of forest dynamics and structure (Billamboz 1996; Leuschner et al. 2000; Billamboz 2003). Information on stand structure and internal competition is embedded in the individual tree-ring series (Cook 1990), but usually hard to extract. Therefore, characteristic tree-ring series from a stand with a specific structure or management system are useful for comparison with tree-ring series from archaeological excavations. By collecting tree-ring series from forests with a well-known structure and management system, it becomes possible to characterise the average growth pattern for an individual tree in such a stand. This characterisation will include information on average ring width and growth rate. Such datasets also permit verification of the standards quoted above for sapwood estimates and the relevance of these to Flanders.

During six archaeological excavations in and around the medieval town of Ypres (Fig. 1), cross-sections of timber were collected for dendrochronological research. The question arose as to whether the observed growth-ring patterns were suitable for dating purposes and chronology building. Therefore correlation measures needed to be sufficiently high and the resulting chronology would have to show a strong common signal. To evaluate whether these tree-ring series were potential records of past management, growth-pattern analyses were performed. Characteristic growth curves were selected and compared with curves from living oaks. Analysis and comparison of such characteristic growth-ring series can yield an impression of the forest structure and dynamics at that time.

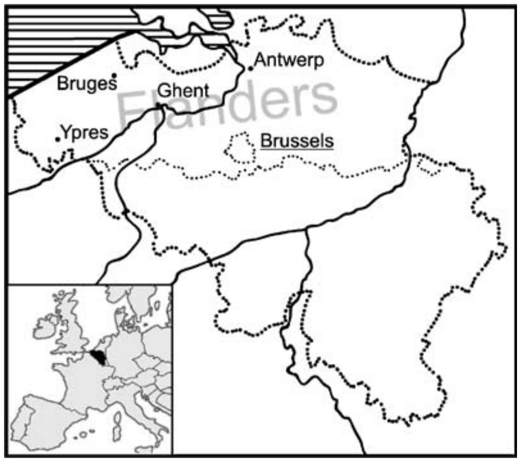


**Fig. 1** Map of Belgium indicating the location of Ypres

## Site description

All the archaeological excavations were situated in or near the town of Ypres. The name of this town was first cited in A.D. 1066. At that time two residential areas were located along a branch of the Ieperlee, a tributary of the Yzer River. Due to the success of the textile industry the population grew considerably and the two settlements merged. From A.D. 1214, the rapidly growing town was walled. The suburbs however, remained outside the defensive wall. In A.D. 1383, during the Hundred Years' War between England and France (A.D. 1337–1453), an English army supported by soldiers from Ghent, in the 14th century one of the most powerful cities north of the Alps, attacked the town and destroyed the suburbs. Although the town itself was never taken, the suburbs were never rebuilt.

## Material and methods

During the period 1993 to 2002, several archaeological "rescue" excavations took place. During two field campaigns dozens of well-preserved wooden structures, parts of medieval residences and patrician and craftsmen's houses, sheet pilings from rivers and a wind mill were recovered. Timber specimens were sampled by taking cross-sections. Prior to sampling, no distinction was made based on dimension or diameter, which ranged from 4 to 50 cm. The cross-sections collected were all saturated with water at the time of sampling. To avoid excessive shrinking the disks were stored in humid conditions using plastic bags. With scalpel and razor blades, a transverse strip was surfaced to make the tree-ring structure clearly visible. Ring widths were measured to the nearest 0.01 mm using a positioning table (Lintab) with associated software (TSAPWin; Rinn 2003) and a stereomicroscope (Olympus SZX12).

In Flanders only a few dendrochronological analyses have been made and are available for comparison/dating purposes. Therefore master chronologies from surrounding regions and countries had to be used: i.e. chronologies covering the Meuse valley (Meuse5) and southern Belgium (Ardennes4) (Hoffsummer 1995), the standard chronologies from Germany (Hollstein 1965; Hollstein 1980; Becker 1981), northern France (Bernard 1998), southern England and East Anglia (Bridge 1988), and the southern part of The Netherlands (Jansma 1995).

To assess the signal strength in the resulting chronology the common variance in synchronised series was analysed. A widely used parameter to quantify the chronology's strength is the *Expressed Population Signal* (EPS) (Wigley et al. 1984; Briffa and Jones 1990). The EPS is based on the mean correlation between all series included in the chronology and has a possible range from zero to one.

$$\mathrm{EPS}(t) = \frac{n\bar{r}_{\mathrm{bt}}}{n\bar{r}_{\mathrm{bt}} + (1 - \bar{r}_{\mathrm{bt}})}$$

Where: $\bar{r}_{\mathrm{bt}}$= mean correlation between all tree-ring series; $n$ = number of correlated trees.

The EPS increases with sample size and with the strength of the mean correlation. Wigley et al. (1984) suggested a minimum value of 0.85 in order to obtain a sufficiently replicated chronology.

At four locations in Flanders, stands with coppiced oaks were selected. Using an increment borer, cylinders of wood were extracted from 2–3 shoots of 15 coppice stools. Using the same technique, 93 cores from naturally regenerated oaks in a forest reserve dominated by *Pinus sylvestris* L. were collected in Mattemburg (The Netherlands). As seedlings, these oaks had been strongly suppressed by the conifers for years. This resulted in very low growth rates and narrow growth rings. Finally, 120 cross-sections from recently cut oaks from two high forests near Brussels (Soignes and Buggenhout) were collected. On each core or cross-section from the three different forest types, ring widths were measured. Cumulative growth-ring patterns were calculated and compared to the series from the Ypres dataset. The total number of sapwood rings was recorded and the associated descriptive statistics, such as range and standard deviation, were calculated.

## Results

Descriptive statistics of the recorded ring-width series for each archaeological site are listed in Table 1. The average ring width and average standard deviation for the individual series do not differ significantly between the different archaeological sites. The same holds for the mean sensitivity of the tree-ring series. This justifies the consideration of the tree-ring series from the five archaeological sites as one dendrochronological dataset.

The average ring width of all individual series within the Ypres dataset is 1.92 mm, with an average standard deviation of 0.76. The large range of observed ring-widths is striking. Ring widths of less than 0.2 mm as well as values up to nearly 1 cm are recorded.

Comparison of the individual series results in low and unreliable correlation values. Short sequences especially disrupt the crossdating process. These short series often show an acceptable visual agreement with longer series at several positions. In only a few cases do the correlation values satisfactorily support one of the synchronisation positions. All doubtful synchronisation positions were rejected, and in the next step the individual tree-ring series were compared directly with the selected reference chronologies. Although statistical measures like $t$-values (Baillie and Pilcher 1973) and coefficients of parallel variation (*Gleichläufigkeit*, GLK; Eckstein and Bauch 1969) are still rather low (e.g. an average $t$-value of 3.71 for all dated series compared to ZD-Becker), they are acceptable due to the fact that the same match positions occur on different reference chronologies. Following this procedure, 74 series (=33.3% of the total dataset) could be absolutely dated. The percentage of successful dating events strongly relies on the number of measured tree rings (Fig. 2a and b). Samples with more than 60 rings could be dated in 50% of all cases. Nevertheless, several series with 30 to 60 growth

**Table 1** Descriptive statistics of the cross-sections from the different archaeological sites

| | No. of samples | Mean ring-width (mm) | *SD* | Range (mm) | Mean sensitivity | Mean series length (years) |
|---|---|---|---|---|---|---|
| Sint Michiel 1 | 120 | 2.11 | 0.75 | 0.18–9.67 | 0.213 | 43.9 |
| Sint Michiel 2 | 56 | 1.66 | 0.68 | 0.15–9.71 | 0.230 | 68.8 |
| Sint Michiel (windmill) | 4 | 1.44 | 0.76 | 0.24–5.55 | 0.223 | 80.0 |
| Ypres, historical centre 1 | 21 | 1.58 | 0.83 | 0.17–7.13 | 0.240 | 82.8 |
| Ypres, historical centre 2 | 21 | 1.94 | 1.02 | 0.55–7.00 | 0.228 | 84.8 |
| Total dataset | 222 | 1.92 | 0.76 | 0.15–9.71 | 0.225 | 57.8 |

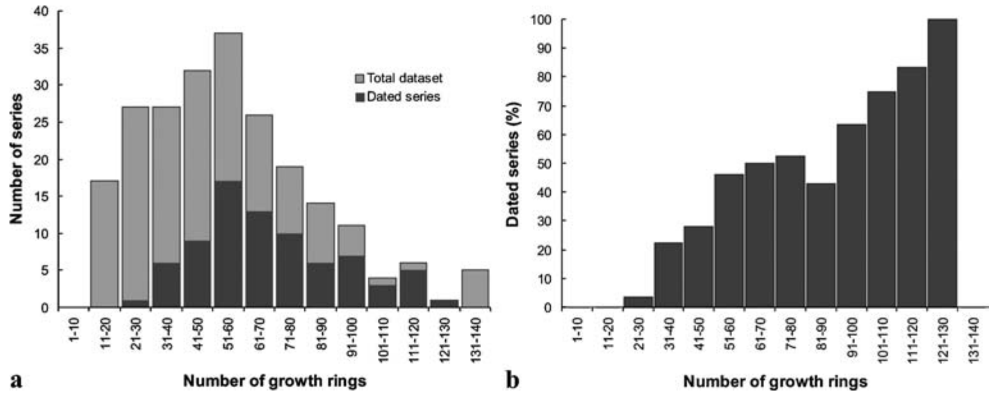


**Fig. 2** **a** Histogram showing the distribution of the number of growth rings from the collected cross-sections; **b** Percentage of dated series according to the total number of growth rings in the samples

**Table 2** Percentage of parallel variation (Gleichläufigkeit, GLK), *t*-values according to Baillie and Pilcher ($t_{BP}$) and cross-date index (CDI) between reference chronologies and the Ypres chronology, and the Ypres chronology built exclusively with short series of less than 60 growth rings (<60)

| Reference (author) | Overlap | | GLK | | $t_{BP}$ | | CDI | |
|---|---|---|---|---|---|---|---|---|
| | Ypres | <60 | Ypres | <60 | Ypres | <60 | Ypres | <60 |
| Meuse5 (Hoffsummer 1995) | 231 | 231 | 78 | 78 | 13.6 | 12.1 | 104 | 94 |
| NL-Zuid (Jansma 1995) | 231 | 223 | 77 | 70 | 13.0 | 11.7 | 93 | 83 |
| Arden4 (Hoffsummer 1995) | 217 | 217 | 71 | 71 | 12.9 | 11.5 | 86 | 78 |
| WD-Eiche1 (Hollstein 1980) | 231 | 231 | 72 | 73 | 10.0 | 9.3 | 73 | 70 |
| WD-Eiche2 (Hollstein 1980) | 231 | 231 | 72 | 73 | 9.5 | 8.4 | 65 | 59 |
| BasPar8 (Bernard 1998) | 231 | 231 | 68 | 69 | 8.0 | 7.6 | 56 | 55 |
| SD-Eiche (Becker 1981) | 231 | 231 | 70 | 72 | 8.4 | 6.9 | 55 | 47 |
| LCE-StOmer (Lavier, pers. comm.) | 125 | 120 | 63 | 61 | 6.5 | 3.0 | 31 | 21 |
| LCE-Calais (Lavier, pers. comm.) | 169 | 164 | 70 | 68 | 4.6 | 5.5 | 32 | 37 |
| S-Engl (Bridge 1988) | 231 | 231 | 59 | 56 | 5.2 | 4.4 | 33 | 28 |
| E-Anglia (Bridge, pers. comm.) | 231 | 231 | 57 | 58 | 3.2 | 3.0 | 21 | 20 |

rings could also be dated. Standardisation with a negative exponential curve, a cubic spline or a combination of both does not ameliorate the dating results. There is no improvement in correlation values, nor in the number of series that can be dated.

After standardising the individual tree-ring series with a negative exponential curve, a chronology was calculated by averaging the resulting indices. This chronology spans the period A.D. 1132–1362 and shows high correlation with the selected references (Table 2). The highest correlation values are found with master chronologies from southern Belgium (Meuse5 and Ardennes4) and the southern part of The Netherlands. Comparison with chronologies from Southern England (S-Engl and E-Anglia) provides the lowest correlation values. The Ypres chronology also displays a significant correlation with ring-width chronologies from archaeological sites near St. Omer and Calais (C. Lavier, pers. comm.), 60–80 km southwest of Ypres, just across the border with France; however the correlation values are lower than those with the German references. Nevertheless, the surroundings and climatological conditions at these locations in France are very similar to these in Flanders.

To assess the signal strength of the resulting chronology, EPS values were calculated. Instead of computing one single EPS value to characterise the whole chronology, running EPS($i$) values were computed for fixed time intervals of 31 years, on each year $i$ of the Ypres chronology. At each point of the chronology a 31-year wide window was superimposed on all synchronised series. The computed EPS($i$) value was then assigned to the central point of the time window (Fig. 3). When more than 14 samples are included in the calculation, the EPS value exceeds the 0.85 threshold

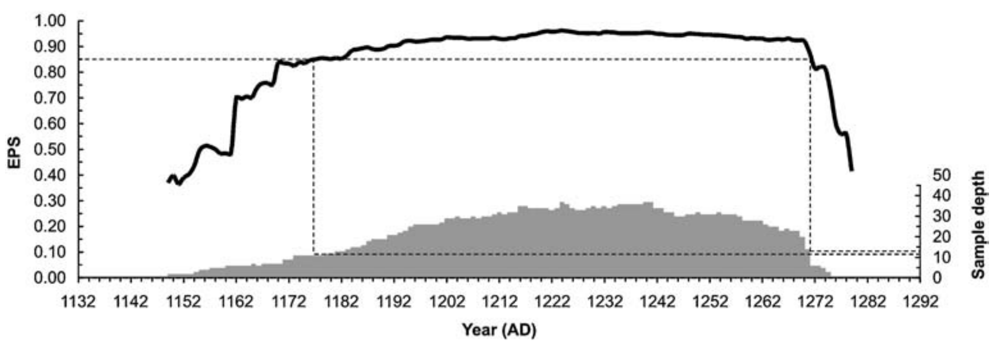


**Fig. 3** Running EPS values and sample depth for the Ypres chronology

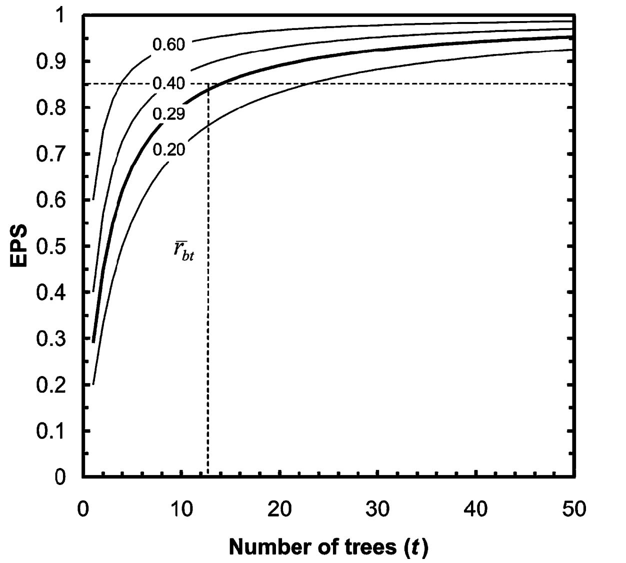


**Fig. 4** Theoretical EPS values for different numbers of trees and several levels of mean correlation

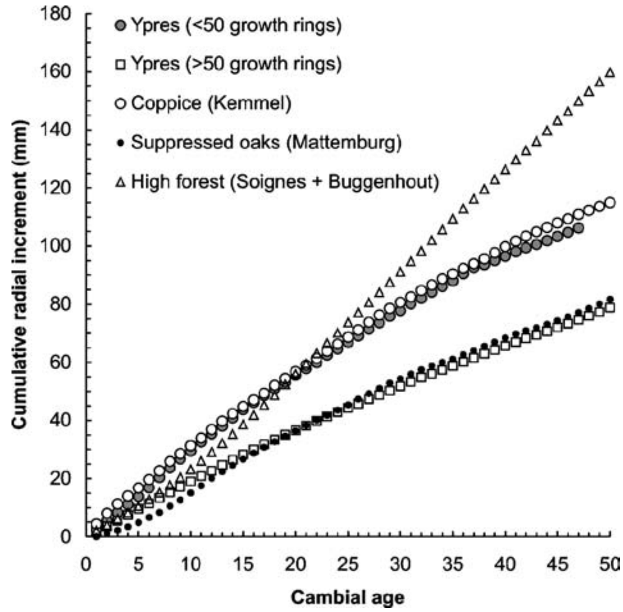


**Fig. 5** Cumulative radial increment of trees with greater and less than 50 growth rings from the Ypres dataset, compared with radial increments of modern coppice, suppressed oaks and oaks from high forest

suggested by Wigley et al. (1984). At one position this level is reached with only 10 samples. A total of 14 samples can be interpreted as the minimum number of samples (sample depth) required when calculating a medieval ring-width chronology for Flanders. The minimum sample depth that should be included in a chronology can also be calculated from the formula defining the EPS by inserting the 0.85 threshold value in the equation. For the samples from the Ypres dataset, the $\bar{r}_{\mathrm{bt}}$ has a value of 0.29 in the interval with the largest number of overlapping series. This results in a theoretical minimum sample depth of approximately 14 trees to reach an EPS of 0.85 (Fig. 4).

Of the cross-sections that were collected from the archaeological sites, 60.4% had less then 60 growth rings. After filtering all samples with less than 60 growth rings out of the dataset a new chronology was calculated, using only these short series. Comparison of this new chronology with the selected references still results in high *t*-values and coefficients of parallel variation (Table 2). EPS values could not longer be calculated since the sample depth was reduced considerably.

The growth rate of the short sequences from the Ypres dataset differs significantly from that of the longer series. All samples with pith, partly preserved sapwood or bark and an estimated number of less than 50 growth rings were selected. The cumulative radial increment was calculated based the cambial age. The cumulative radial increment was also calculated for all series with pith and more than 50 growth rings (Fig. 5). Significant differences between these two types of series can be seen in their growth curves. As early as in the juvenile stage a considerable difference in growth rate is noticed. The difference in growth rate slowly decreases with increasing age of the trees. Adding similar tree-ring series data from modern coppice, high forest and suppressed oaks, it is obvious that the short Ypres sequences show a very high similarity with the coppice. The growth curve of the longer Ypres series on the other hand corresponds best to the suppressed oaks.

The number of sapwood rings was recorded from contemporary oaks from three specific types of woodland: shoots of a coppice stool, high forest and suppressed oaks in a stand dominated by *Pinus sylvestris* (Table 3). According to the total number of growth rings, each individual was assigned to an age class of 50 years. Within these age classes the mean number of sapwood rings was calculated and plotted against the widely applied standards for Western Europe. In the age class with the youngest trees, i.e. up to 50 years old, a considerable difference is noticed between the standard of 16 sapwood rings and the observed number of sapwood rings, only 6.6. When shoots are allowed to grow beyond 50 years, the number of sapwood rings rises to the standard estimate. For older trees, up to 200 years, the mean number never differs more than six years from the standards, and falls within the range of the standard deviation.

With all dated series, a chronology was built for the archaeological sites in and around Ypres. This Ypres chronology now spans 231 years starting from A.D. 1132. The earliest felling date, calculated from the oldest wood sample with completely preserved sapwood, is A.D. 1199. The most recent felling date from a similar sample is A.D. 1316. This indicates that, at least during a period of 117 years, construction activity took place at these locations. According to the distribution of the felling dates, this construction activity was most intense from A.D. 1240 up to 1290. After this last date, there is a significant reduction in the number of dated tree-ring series.

## Discussion

Up to now, only a few dendrochronological projects have been undertaken in Flanders for dating archaeological

**Table 3** Mean number of sapwood rings for oaks growing under specific conditions, compared with the prevailing standards for Western Europe

| Age class | Coppice | High forest | Oak under pine | Standards for Western Europe |
|---|---|---|---|---|
| Mean ± SD | | | | |
| 1–50 | 6.6±2.3 | 13.0±5.3 | 19.5±2.5 | 16±5 |
| 51–100 | 16.9±4.6 | 19.7±5.9 | 18.1±4.8 | 16±5 |
| 101–150 | – | 26.7±7.8 | 16.7±5.2 | 20±6 |
| 151–200 | – | 22.2±6.1 | – | 20±6 |
| 201–250 | – | – | – | 26±8 |
| Range (min–max) | | | | |
| 1–50 | 5–13 | 7–20 | 17–22 | |
| 51–100 | 10–26 | 9–37 | 9–31 | |
| 101–150 | – | 13–47 | 12–23 | |
| 151–200 | – | 15–34 | – | |
| 201–250 | – | – | – | |
| Sample depth | | | | |
| 1–50 | 13 | 4 | 3 | |
| 51–100 | 20 | 47 | 87 | |
| 101–150 | – | 53 | 3 | |
| 151–200 | – | 16 | – | |
| 201–250 | – | – | – | |

wood. Successful dating was almost completely restricted to imported timber from the Baltic (e.g. Houbrechts and Pieters 1996; Haneca et al. 2005). The potential for such dendrochronological research on Flemish oak was unclear and had been discussed. The combination of the lack of reference chronologies for this specific area, the high anthropogenic influence on forests since the Roman era and the tempering influence of the Atlantic climate made investments in dendrochronology as a dating tool risky. Moreover, the amount of preserved wood from archaeological excavations is often rather low. The rich collection of wood recovered during archaeological excavations in Ypres provided the opportunity to verify the potential of dendrochronology as a dating tool for medieval archaeological sites in Flanders and for the development of a procedure for a dendrochronological approach adapted to the reality of Flanders and comparable regions throughout Europe. The average ring width of 1.92 mm suggests that these oaks experienced favourable conditions, resulting in a high growth rate. The typical weather patterns in Flanders, with mild winter temperatures, moderately warm summer temperatures and abundant precipitation (approx. 750 mm), rarely lead to stressful conditions for oaks. Mathematically, this is expressed in the low mean sensitivity of the tree-ring series from the Ypres dataset (Table 1). Mean sensitivity can be considered as an indicator of the responsiveness of trees to the prevailing environmental conditions (Fritts 1976). Since these hardly ever limit growth, response to the mild Atlantic climate is hard to quantify. Additionally, soil fertility and especially stand density must also have had a considerable influence on radial growth.

The large range of ring widths (0.2–9.7 mm) is probably influenced by the many abrupt growth changes that are observed in a large number of series. Since man intensively exploited medieval forests in Flanders, these abrupt variations are likely to be related to logging activity or management interventions.

It has been demonstrated that even short sequences with less than 60 growth rings can be dated. Nevertheless, a strong correlation between the number of measured tree rings and successful dating was observed (Fig. 2b). Only when an oak sample has more than 60 growth rings does the chance of successful dating rise above 50%. Nevertheless it needs to be emphasised that dendrochronological dating in these specific conditions is laborious and needs a sufficient number of wood specimens to lead, successful and acceptable dating of the tree-ring series. 'According to Briffa and Jones (1990), an EPS value of 0.85 can be achieved by as few as four trees in semi-arid conifer stands in western USA. On the other hand a sample depth of at least 25 trees can be necessary in deciduous sites in the UK. For Flanders at least 14 dated medieval wood samples ought to be available to calculate a robust chronology. Combined with the calculated percentage of dated series according to the total number of growth rings (Fig. 2b), an estimate can be made of the minimum number of wood specimens that should be collected from each construction phase on an archaeological site, when chronology building is one of the main goals. For example if most wood samples show 61–70 growth rings, at least 28 samples (=14/0.50) should be collected and measured. When the observed tree-ring series are longer, e.g. 91–100 years, this number decreases to 22 (=14/0.64).

Growth patterns of shoots from modern coppice are the most similar to the growth pattern of short series from the Ypres dataset. In particular the first growth rings of the short series from Ypres and the modern coppice display a vigorous growth (Fig. 6). This contrasts with the low growth rate of the longer series from Ypres and the oaks generated from acorns (suppressed oaks from Mattemburg). It is obvious that shoots from a coppice stool (vegetative regeneration) will demonstrate a larger growth rate compared to that from generative germination from a seed. In the first year, seedlings of pedunculate and sessile oak reach an approximate height of respectively 20 cm and 16 cm, while a shoot from an oak stool grows up to 2 m, and reaches a thickness of 2.5 cm (Vera 2000). These data suggest that the timber with short tree-ring series from Ypres comes from shoots from coppice stools. The first

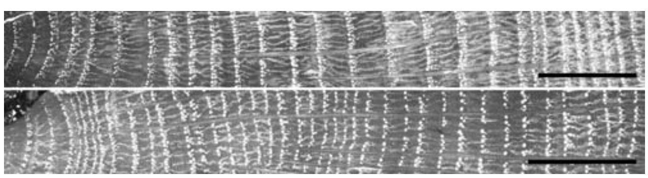

**Fig. 6** Ring-width patterns of two cross-sections from the archaeological excavations at Ypres that display different growth trends. The growth pattern of the upper image shows wide rings, while the other cross-section displays a more uniform growth pattern of smaller rings. Earlywood vessels were filled with chalk in order to highlight the growth-ring boundaries. The scale bar represents 1 cm

growth rings of the longer series from Ypres demonstrate that these trees probably regenerated from acorns, and not from a coppice stool. All this agrees with written sources on medieval woodland and forest use (e.g. Buis 1985; Rackham 2003). During the Middle Ages coppicing became a popular silvicultural technique (Bechmann 1990; Rackham 2003). Cutting trees and shrubs like oak (*Quercus* spp.), hazel (*Corylus avellana* L.), ash (*Fraxinus excelsior* L.) and willow (*Salix* spp.) to ground level allowed a vigorous re-growth, resulting in a sustainable supply of timber. An adaptation of this technique is coppice-with-standards, a two-story woodland with coppice and some trees left to grow as large size timber, called "standards". This type of woodland management yields a large spectrum of forest and timber products.

The anomalous growth-rate changes that are observed in the tree-ring series from the Ypres dataset might be a result of logging activity. Bridge et al. (1986) measured the growth pattern of oaks in the Bradfield woods (Suffolk, UK). This stand is described as coppiced woodland. Oak trees are treated as standards while the understory of ash, hazel, birch (*Betula* spp.) and alder (*Alnus glutinosa* L.) is coppiced on a regular basis. Bridge et al. observed that after coppicing the understory, the growth rate of the retained oaks increased suddenly by 20% compared to the year prior to coppicing.

When calculating the mean number of sapwood rings, management practices and growth ratios are hardly ever considered. If in medieval times, forest structure differed significantly from the present, sapwood estimates could be biased when using tree-ring series exclusively from primary forests. Comparison of sapwood counts from modern oaks with the prevailing standards for Western Europe does not show large differences, except in one situation. Based on the available data, sapwood estimates differ significantly for young shoots (less than 50 years old) from coppice stools. Here a mean of $7\pm2$ sapwood rings is the best estimate, in contrast to the prevailing standard of $16\pm5$. An important factor that emphasises the observed difference is the fact that only one sapwood estimate is available for a broad age class of 100 years. The recorded sapwood counts demonstrate that age classes of 50 years are more appropriate for sapwood estimates, especially for trees less than 100 years old.

Although conditions in Flanders are suboptimal for dendrochronology these results show that tree-ring analysis can help to document historical records of forest management and structure. From raw tree-ring series, impressions of medieval forest structure and dynamics can be derived. Furthermore, successful application of dendrochronology as a dating technique is demonstrated. This should encourage further combined dendrochronological and archaeological research in regions with a high historical anthropogenic influence on the original forest cover. In particular the creation of a regional reference chronology for Flanders would increase the potential of dendrochronology for dating purposes.

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