Age of Big Oaks in Tallinn, Estonia

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There are big oak trees growing mostly in three districts of Tallinn - Park of Kadriorg, Kopli, and the City of Tallinn. Age of twenty-one oaks of remarkable size from these areas was determined using different methods: graphically on the basis of radial increment data of wood (with extrapolation of increment in the core to the radius gap), and by using a bark method elaborated by M. Rohtla. The calculated tree ages were matched with known written references on the history of the estates.

It was determined that most of the oak trees studied were older than the parks or estates where they grow today. In the popular Park of Kadriorg (established in 1718) there are still oaks alive originating from the pre-park period. Their age exceeds 300 years. The thickest and oldest living oak tree in Tallinn was found in the park of Kadriorg, with trunk perimeter 520 cm at breast height and age about 360 years (onset about 1640 AD).

The graphical method of age determination as well as the accuracy of the original bark method by M. Rohtla needs to be refined and checked on further material.

Key words: age of oaks, tree-rings, bark method, Tallinn

Introduction

We live in a multi-dimensional world. The geographical environment of biological beings is three-dimensional. The fourth, temporal dimension of biological objects is often neglected as too difficult to investigate. For a spectacular tree, its height and girth of stem can be easily measured. What about a tree age? Age of big trees usually exceeds age of humans. That is easy to state when anybody's grandfather already knew a tree. The question of tree age could be more precisely answered by counting tree-rings, the annual wood layers in the stem of a tree.

In the practice of determining age of big trees the researcher meets challenges even in the case of trees growing in Temperate Zone. First, presuming that generally trees form one tree-ring every year, we have to be able to distinguish these wood layers to count them. Tree-rings of temperate conifers and ring-porous deciduous angiosperms (e.g. *Quercus*) are usually distinct, whereas tree-rings of diffuse-porous species (e.g. *Tilia*) are barely visible. Second, locally missing rings can occur in the stems of some tree species and on some sites. These missing rings have to be discovered and recorded, to count all the tree-rings in a stem. Third, there can be double rings in some trees, which have to be discovered and corrected as well. There are certain features and techniques to detect these wood anomalies. We do not discuss these techniques in this paper.

Fourth, in the case of thick stems of big trees normal increment borer of 40-cm length does not reach pith of the stem. Taking into account that the borer can be inserted into a stem not more than 39 cm, we can find the maximum girth of trunk for reaching pith – it is 245 cm. Age of thicker trees can not be counted from tree-rings from bark to pith.

Fifth, there is one more serious obstacle in determining the age of big trees: very often the trunk has hollow inside, so that there is even less than 39 cm of intact wood surrounding the hollow. For this case we have developed an age calculation method based on analogous growth of younger trees of the same species and site conditions.

The capital of Estonia, Tallinn, is well known by its old trees. Some of the trees are planted and a part of them are of natural origin. In the 17^{th} century trees were planted around several summer estates and also on Kopli peninsula. The latter was known for its forest since mediaeval times. Some of these trees are still alive. Many ancient trees are growing in the Kadriorg Park, established in 1718. There are old maps and written sources indicating oaks growing on the territory of today's Tallinn already centuries ago. During ages oak trees have been appreciated in Estonia as hard and strong trees. Often oaks were holy trees for old Estonians; they were planted and cared for. Therefore oak trees growing near households are often related to the establishment of an estate or a mansion. In some cases such trees can originate even from earlier period, as remnants of forest in a new established park area. It is not so reliable to speculate the age of trees by their outlook. For explaining the history of old parks and checking the origin of some big trees, remarkable oaks growing in Tallinn were chosen for this study. Several methods were used for assessing the age of old oaks and the results were matched with known written data.

Material and methods

Twenty-two big oak trees (*Quercus robur* L.) were cored in the parks and green areas in Tallinn to determine their age. From most of these trees also bark samples were extracted for age determination. Most of the sample trees are notable for their size. Some thinner oak trees were cored to see the beginning of the age trend of the radial growth. The girth of the oaks was measured as well as the thickness of bark. Perimeter of the cored oaks fluctuated from 198 cm to 520 cm. The oak trunks are covered with bark of thickness 20 to 74 mm. Each oak was cored at height of 1 to 1.4 metres, depending on the shape of individual trunks. The direction of coring was also recorded; it was chosen to sample the most symmetric part of the trunk.

It appeared that in most cases the corer did not reach the pith in thick tree-trunk or, more common, the trunk was hollow or decayed inside. In these cases we have only the outer portion of radius at our disposal. In five thinner oak trunks we succeeded in boring nearly to pith. These cores served for complement of the first part of the age trend of oak increment, beginning from the axis – the pith of the trunk (Fig. 1).

The length of the raw cores was measured and tree-rings counted in every core. It was important to measure the cores immediately, because the length of oak cores decreases when drying. Our experience has shown that length of oak cores on average decreased 1.3–4.6 % in room temperature (about +20° C) during a stay of one month. In eight samples, including the cores of the thinner trees, the tree-rings were not only counted but also their width was measured under a

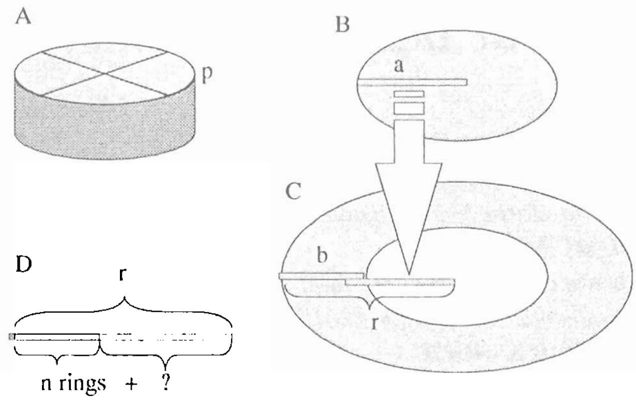

Figure 1. A, B. Ring widths of a thin and young tree serve as complementary for estimating age of a thick and hollow tree (C). D: Radius of a big tree (r) is only partly covered by an increment core; the number of annual rings in the rest of the radius (?) has to be estimated by using a core (a) from a thinner tree as a model of growth rate. As longer the core covered part (b) of the radius, the reliability of the age assessment is higher. p - perimeter of trunk, to be measured for calculating the radii.

binocular microscope. These measured tree-ring series were depicted graphically as cumulative increment curves (Fig. 2). While determination of trees' age by their radial increment has been practised in Estonia for decades already (Läänelaid, Vahtre, 1976; Läänelaid, 1979, 1982, 1998, 1998a, 1999), the graphical method of extrapolation of growth curve by the first author is new here.

Technique of calculating the age of thick oaks was the following. From the perimeter the radius of the trunk was calculated. Thickness of bark was subtracted from the radius to get the radius of xylem (wood). The length of the raw core was then subtracted from the radius of the xylem. The difference is the radius gap with no tree-rings preserved. There were two versions used to fill that radius gap:

1) Assumed that the average ring width both in the core and in the rest of the radius is the same and the former was extrapolated to fill the radius gap;

2) Assumed that increment rate in the inner part of the trunk is analogous to the increment of thinner trees growing in the vicinity and the radius gap was filled by their tree-rings.

The extrapolation was carried out on the graphs of cumulative radial increment of the trees (Fig. 3). The corresponding length of radius of the young oaks was continued by the cumulative increment trend of the older oak. The latter was fitted in the graph so that the curves would join smoothly. It means that we presume the same average growth rate immediately before the end of the curve of the younger tree and in the inner section of the core of the older tree.

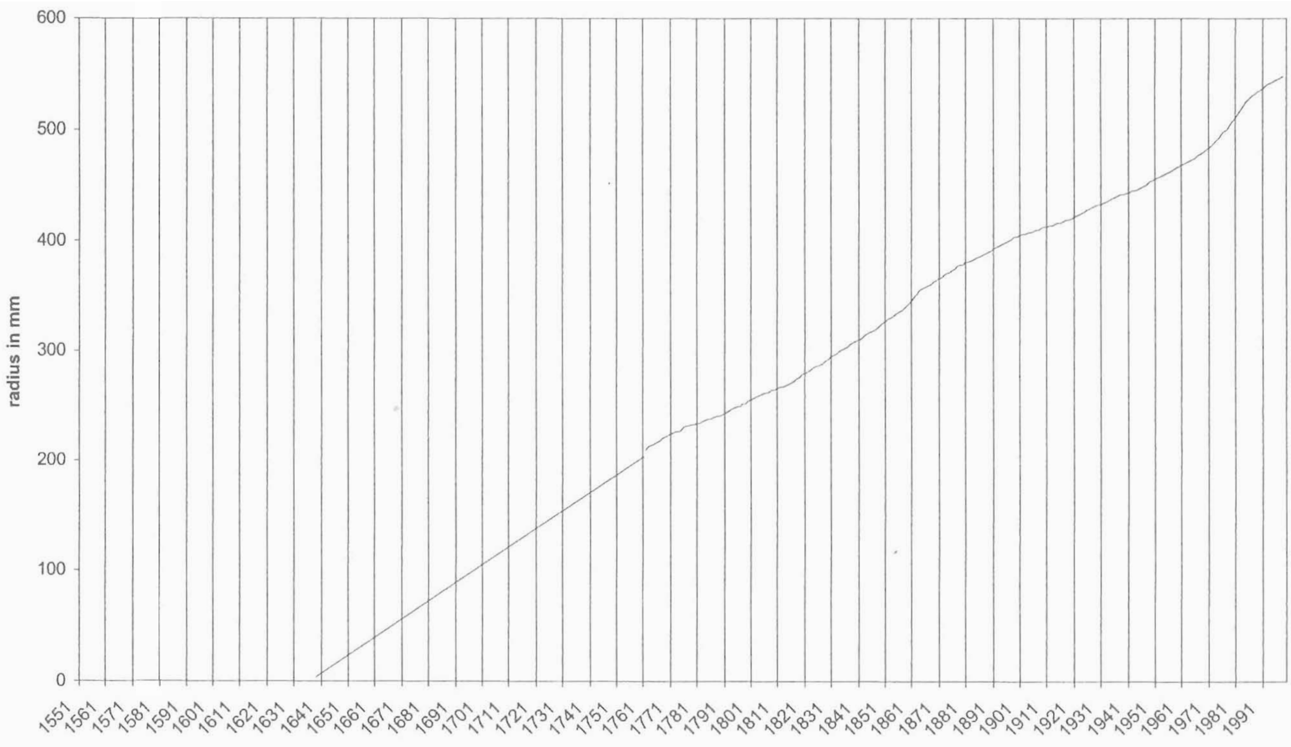

Figure 2. The direction of cumulative increment curve (prolonged by dashed line) indicates the point on abscissa where radial growth of the tree probably started in a certain year (the onset year). Age of the tree can be read graphically.

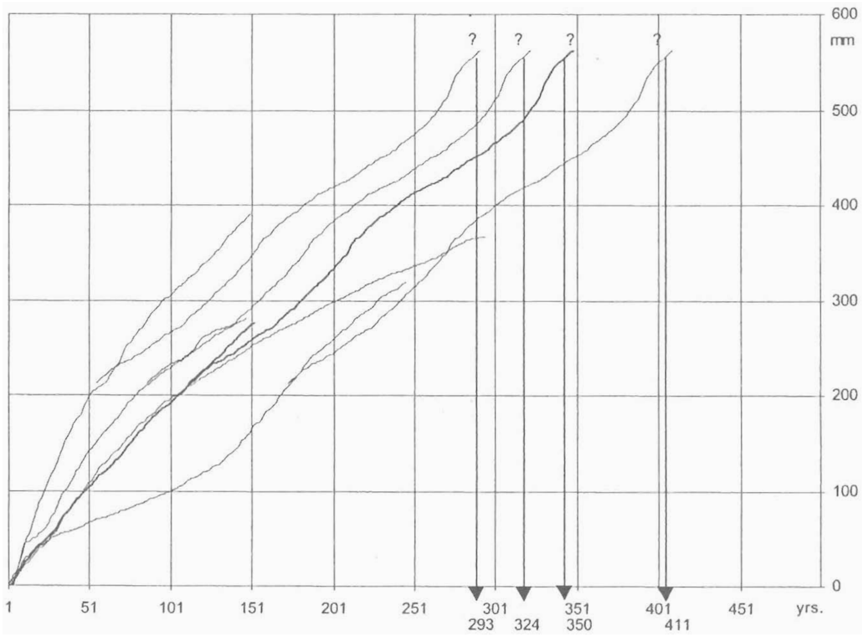

Figure 3. The cumulative increment curves of young trees are matched with cumulative increment curve of an old hollow tree and the most probable version will be selected to establish the age of the big tree. Abscissa - years (possible ages of the old tree pointed by arrows), ordinate - radius of tree trunk in mm.

In all cases the tree age was calculated as age of the tree at breast height, 1.3 m above ground. There was no sense to add the years for growing from acorn to breast height because 1) we do not know that period precisely (assumedly it is about 8-10 years for oak seedlings), 2) in the case of parks the trees planted there were probably 1.3 metres high or more. Thus the age of a tree at breast height is indicating rather the planting year than the age of the tree germinated from seed (Fig. 4). All age estimations were rounded to the nearest decade.

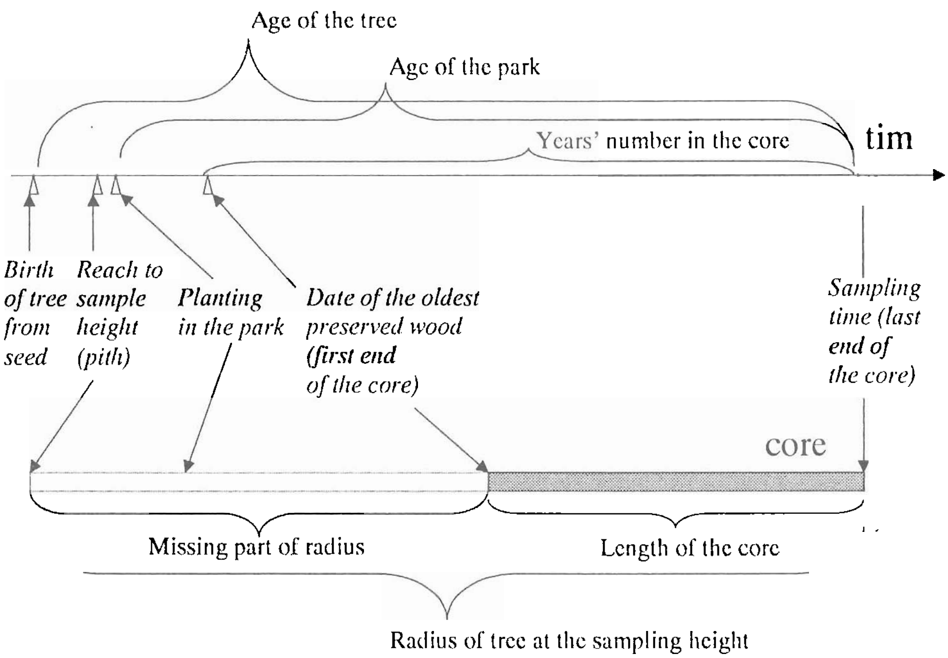

Figure 4. Dates of life of a tree that can be assessed from an increment core of a tree growing in a park

For comparison, age of most of the oaks was calculated also using the bark thickness – a new method for assessing age of trees introduced by Mart Rohtla. In this method we mean 'bark' as all the tissues laying outside the cambium (including both phloem and periderm). Details of the method for determining age of oaks and limes by thickness of their bark and perimeter of trunk are described (Rohtla, 1998).

It is well known that a tree grows thicker from cambium which lays between xylem (wood) and phloem (bark). Growing xylem forms annual growth layers which we call tree rings after their appearance in the cross-section of tree-trunk. Analogically, cambium forms bark tissues outside, although not so fast as wood tissues inside. In some tree species older (i. e. outer) layers of bark - periderm - drop away and only younger (i. e. inner) part of bark preserves on the tree-trunk. In others, e. g. oak and lime, periderm splits into 'ribs' but can preserve on tree-trunk hundreds of years. Often bark of oak preserves even better than wood inside trunk. In cross section of oak bark there are also increment layers which are attributed to annual growth. These layers are very thin and cannot be distinguished by naked eye. On well-polished surface of dry bark sample thin annual layers of fibres and sclereids become visible and countable. Counting of these bark layers under magnification yields us age of the bark in years.

Actually, thickness of bark of big oaks is often a little decreased due to mechanical weathering during decades and centuries. The shape of bark ribs and cracks shows the possible loss of bark due to weathering. Sometimes bark ribs are better preserved in the upper part of the tree-trunk. If necessary, bark sampling can be made from higher part of the oak trunk than the ordinary 1.3 metres from ground level. Degree of weathering of bark is assessed by the shape of rays in the cross section of the bark rib. Rays in the outer part of a non-weathered bark rib are going close together. Thickness of missing part of bark was expressed in number of annual layers. The approximate number of weathered annual layers of bark was added to the counted number of bark layers. To this number age of oak of sampling height can be added, to get the age of oak from seed to present. Sum of these three numbers is regarded as the approximate age of oak, yielded by bark method. In this study only probable number of weathered bark layers was added to the counted number of bark layers. The sum means age of oak from 1.3 m tall.

For sampling bark of oaks an original bark corer was used by M. Rohtla. This saw-teethed hand corer removes a cylindric piece of bark with diameter 18 mm. Thickness of sampled bark (length of corer tube) can be up to 120 mm. Bark hole with diameter 20 mm left in the trunk was closed with a cork. Bark cores were dried, transversal surface of them smoothed and carefully polished. Bark layers were counted under magnification.

Results and discussion

1. Oaks in the territory of Park of Kadriorg

The Kadriorg Park lies in the eastern part of Tallinn. Once established as a residency area of Russian tsar, it is now a popular green area of 70 hectares with shadow trees, a water pool and several monuments along the seashore. Palace of Kadriorg in the park serves as National Art Museum of Estonia and residence of the president of the Republic of Estonia. Measured data of oaks are given in Table 1.

Table 1 Sampled oaks growing in the Park of Kadriorg, Tallinn

Sample No. and direction	Location of the tree	Sampling date	Perimeter of trunk, cm	Thickness of bark, mm	Length of raw wood core, mm	Number of tree rings in the core
1 W	Weizenbergi 26	19.08.99	520	74	324	198
2 W	Weizenbergi 26	19.08.99	353	63	348	195
3 W	Weizenbergi 26	19.08.99	214	41	316	244
4 W	Weizenbergi 26	19.08.99	339	54	353	196
5 W	Weizenbergi 26	19.08.99	388	62	352	231
6 E	Behind Palace of Kadriorg	19.08.99	383	60	341	238
7 NE	Park of Kadriorg	19.08.99	352	60	360	264
8	Park of Kadriorg	19.08.99	272	63	197	218
9 SW	Park of Kadriorg	19.08.99	505	60	348	153
	Park of Kadriorg	19.08.99		60	379	
11 SW	Park of Kadriorg	19.08.99	384	60	346	198

Five thick oak trees were studied which grow near the house Weizenberg St. 26 in the Kadriorg Park. It appeared that the thinnest oak tree of these five trees had the narrowest tree-rings, on average 1.3 mm, whereas others' average ring width in the cores was 1.52 to 1.80 mm. The thickest oak (No. 1) is evidently older than the others. Presuming that the average increment has been the same in the whole radius, age of the tree would be estimated to 460 years. Presuming that in young age of the tree its tree-rings were wider, we have found that the approximate age of the oak can be not more than 450 years. In any case, the increment core with counted tree-rings covers only less than half of the radius of the trunk. The age of the big oak can be twice as much as the counted number of tree-rings in the core, 198 rings, i.e. about 400 years or less. The bark method of determination of age gave age of 310-330 years for this oak. So we resume the probable age of this big oak at breast height (about the size while planting) being approximately 360 years old in 1999.

There is a legend known that two oak trees were planted (one of them disappeared for now) by Russian tsar Peter the Great at the area of nowadays Weizenberg St. 26. One of these oaks would just be the tree with perimeter 520-cm. But its probable planting time appeared to be about 1640 AD. It is much earlier time than the known years of establishment of the Kadriorg park since 1718 by Peter the Great. There may be several interpretations of the result:

1) The actual age of the oak is still much less, about 280 years, and Russian tsar planted the tree;

2) Age of the big oak is nearly 360 to 400 years and it grew there naturally before the establishment of the park already.

In the case of age 280 years the average ring width in the inner part of the radius should have been 5.2 mm during 82 years. It is very wide increment compared with the average ring width of a neighbouring younger oak tree (1.3-mm). Thus more probably oak No. 1 at Weizenberg St. 26 is still about 360 years old and originates from a natural stand long before the establishment of the Kadriorg Park in 1718.

Age of the rest four oaks near the house was found to be close to each other. By extrapolating the average ring width to the rest of the radius, the approximate possible age range of the oaks was found: 230 to 360 years. In the premise of wider rings inside the trunk, the actual age should be even less. Except oak No. 3 with approximate age of 260 years, the other three oaks can be roughly 280 years old and thus probably planted in the park in or soon after 1718 AD. The bark method gave age of 270-330 years for these oaks.

There grows one big single oak (No. 6) in the garden, just behind the Palace of Kadriorg in the park. Extrapolating the same increment rate to the inner part of the trunk, the approximate age of the oak was found 384 years. In the assumption of better increment in the youth of the tree, the presumed age of the oak is about 360 years, the tree extending back to 1640 AD. It is nearly 80 years before the establishment of the Kadriorg Park in 1718. If we accept the tree age of ca 360 years, it would be hardly probable that an 80-90-year-old oak tree was planted in the park in 1718. Also it is not feasible that the tree is much younger and was planted there as a small tree in 1718; in that case it had to have average ring widths 4.98 mm in the inner part of its trunk. The big oak in the garden behind the

Palace of Kadriorg is probably older than the park and the Palace itself, with age about 360-370 years in 1999, originating then from 1630-1640 AD. It is a remarkable tree for its size, age and also for its central location in the garden of the residence of the President of the Republic of Estonia.

Six big oak trees more were sampled by increment borer in the Park of Kadriorg. Oak No. 7 in the park has two trunk branches. Extrapolating the same average ring width to the whole tree radius, the approximate age of the tree was 366 years. Reconstructing the age graphically, the assumed age due to wider tree-rings in the youth of the oak was about 340 years. This estimation is more probable. According to this age, the oak tree was 1 metre high in about 1660 AD and therefore older than the Kadriorg Park.

One of sampled trees (No. 8) was a felled dried oak trunk lying in the park. It was possible to core the lying trunk at height about 6.5 m. In that core 292 tree-rings were counted. The core reached nearly to the pith of the trunk. At the height of 1.0 m above ground another increment core was extracted. A total of 218 tree-rings were counted in that core. The extrapolated age of the tree in the assumption of the same average ring width was found as 409 years. As we know that usually the rings are thinner inside the trunk, the actual age of the tree is much less (it would be unbelievable that the oak tree has grown 190 years from the height of 1 m to the height of 6.5 m). The graphically reconstructed age of the tree at 1.0-m height was about 310 years. It means that it took about 22 years to grow from the height of 1 m to the height of 6.5 m. Even that growth rate may be underestimated (25 cm in length per year). We conclude that the oak tree was nearly 300 years old in 1999, originating from about 1700 AD. The bark method showed age of 270-290 years for that oak. In any case that oak tree was older than the Kadriorg Park, as it was already taller than 6.5 m in the year of establishment of the park in 1718 AD.

The next sampled oak, No. 9, appears to be the fastest growing oak in the Kadriorg Park, yielding the average annual thickness increment 2.27 mm. The given average ring width is the same through the whole radius, the age of this oak was 326 years. The given rings were wider in the youth of the tree, we reconstructed graphically the estimation of the age ca 300 years. The latter estimation seems more reliable. As the previous oaks, this tree originates from the pre-park period too.

Oak No. 10 was represented by a stump from which a core was extracted. The probable age was calculated from the radius as 248 years for the case of the same average ring width and as 210 years for the case of wider rings inside. The latter result is more probable. This cut oak was probably planted in about 1780 AD, several decades after the establishment of the park in Kadriorg in 1718.

The age of oak No. 11 was first calculated assuming the same average ring width in the inner part of the trunk: the approximate age of the tree was found to be 315 years. Assuming wider rings inside the trunk, the age was reconstructed graphically as ca 310 years. The bark method revealed age of 270-290 years for this oak. As most of the previous sampled oaks in the Kadriorg Park, the estimated age of this tree exceeds the age of the park itself and the trees probably originate from a pre-park stand.

Our investigation of age determination of several thick oak trees in the Kadriorg park confirms the view that there were oaks growing in the place before establishing the park in 1718 AD by Peter the Great. Several researchers have noted natural oak growth in the area before 1718 (Schwerin, 1926; Viirok, 1932). In the middle of 1920s a dried oak tree was felled in Kadriorg and about 300 tree-rings counted in the cross-section (Viirok, 1932). It makes the tree's onset in 1620s.

It is known that there were several summer manors in the area in the 17th century already. The first one of them was apparently on the territory sold to Hermann Roemer in 1629 and further probably in 1662 to Heinrich Fonne (Sander, 1993). That summer estate probably involved also the growing area of these oaks. Thus planting of oaks is not excluded too. The oldest trees in the park may be of natural origin as well. In his articles E. Viirok (1930, 1932) says that the oldest oak trees have stood here since before the establishment of the park. Extensive planting was started in 1718, when larger trees together with soil were carried to Kadriorg from manor parks nearby. Lime-trees, horse chestnuts, fruit trees and oaks were planted then in the park.

2. Oaks in Kopli peninsula

The nowadays town district Kopli in the north-west of Tallinn was known by its old oak growth since mediaeval times. Kopli was mainly famous for the oak wood, which, to a great extent, was destroyed during the siege of Tallinn in 1570-1571 in the days of the Livonian War. The first act concerning afforestation in Tallinn was enforced in 1611: a landholder in Kopli was charged to plant 300 young oak trees. Tenants of Kopli were required by the municipal administration to plant trees in that district even later (Sander, 1998).

There are several remarkable single oak trees growing in this district of Tallinn. Some of them were sampled for age determination (Table 2).

A big oak tree in the centre of a loop of streetcar rails (No. 12) has trunk evidently partly rotten and

Table 2. Sampled oaks growing in Kopli peninsula, Tallinn

Sample No. and direction	Location of the tree	Sampling date	Perimeter of trunk, cm	Thickness of bark, mm	Length of raw wood core, mm	Number of tree rings in the core
12 S	Kopli, loop of rails	19.08.99	507	62	371	180
13 S	Ship Repair Factory	19.08.99	474	50	367	184
14 SE	Kaluri 2	19.08.99	405	53	286	172
15 S	Former cemetery	19.08.99	410	40	378	221

hollow inside. Assuming the same average ring width throughout the trunk, the approximate age of the oak was 360 years. Taking into account the assumed wider rings in the centre of the trunk, the approximate age according to graphic reconstruction was approximately 320 years. The latter result has to be considered more probable. It is curious that the bark method has yielded even more modest age for this oak – 210–230 years. There are no known written data about the origin of this oak.

Another big oak with trunk perimeter 474 cm grows on the territory of the Baltic Ship Repair Factory in Kopli (No. 13). Assuming the same average growth rate throughout the trunk, the approximate age was 350 years. Assuming wider tree-rings inside the trunk, the approximate age of the tree was 300 years. The bark method gave 250-280 years for that oak. The history of this oak is unknown.

An oak tree at Kaluri St. 2 in Kopli is in bad condition, with dry treetop and damaged trunk. In assumption of equal growth rate in the whole radius the approximate age was 355 years; in assumption of wider rings inside the approximate age was reduced to 270 years. Of these two estimations the latter has to be considered more probable. According to the bark method, age of the oak is 270-300 years.

A big oak tree (No. 15) grows in the former cemetery of Kopli. The cemetery was destroyed and a park was established there in the Soviet period in 1951-1961. The cemetery of Niguliste Church was found there in 1774. This oak is the biggest preserved tree of the cemetery. The tree is damaged but still powerful. Sample core shows that this oak has grown more slowly than the other analysed big oaks in Kopli. Assuming the same average ring width in the whole trunk, the approximate age of this tree would be 358 years. Assuming wider rings inside the trunk, the approximate age was reduced to 290 years. The latter means the zero-year ca 1710 AD. The bark method gave 375 years of age for that oak. So the age of this oak surely exceeds that of the cemetery. Probably this is the only tree in the park today, originating from the time before the foundation of the cemeterv in 1774.

3. Oaks in the area of the City of Tallinn

Measurements of sampled oaks from the area of the City of Tallinn are given in Table 3.

Table 3. Sampled oaks growing in the city of Tallinn

Sample No. and direction	Location of the tree	Sampling date	Perimeter of trunk, cm	Thickness of bark, mm	Length of raw wood core, mm	Number of tree rings in the core
16 S	Garden of Kühnert	29.10.99	250	26	381	146
17 S	Garden of Kühnert	29.10.99	198	38	267	148
18 E	Toomkuninga 13A	29.10.99	474	65	335	108
19 S	Falk Park	29.10.99	263	20	339	127
20 N	Adamsoni 2B	29.10.99	268	40	359	180
21 W	Adamsoni 2B	29.10.99	270	35	345	168
22 NW	Harjumägi hill	29.10.99	207	25	274	143

Two oaks in the former garden of Kühnert, now Sakala St. 23, were analysed. Both cores reached near to the pith of the trunk. Assuming the same average increment in the small absent part of the radius, the age of the trees was about 150 and 152 years; presuming somewhat wider rings in the centre of the trunk, the ages were 148 and 150 years, respectively. The difference can be neglected as not significant. We found that these two oaks of different thickness have the same age, about 150 years, hence originating from 1850 AD. The bark method resulted with the same age, 140-150 years, for the second tree.

These two oaks are growing in a former garden of Wilhelm Kühnert (1819-1891), the chief forester of Tallinn (Sander, Meikar, 1996). W. Kühnert had bought this area in 1862 and started to found a garden here. The 13 years difference between the established age of the trees and the foundation year of the garden may mean that 1) Kühnert had planted young oaks of several metres high (having grown 13 years after reaching the sampling height 1.2 m) or 2) smaller and younger trees were planted by the previous owner of the ground a few years before selling the property. In any case, the age of the oak trees is very close to that of the garden of Kühnert.

A big oak in the yard of a kindergarten, Toomkuninga St. 13A, was the next. The trunk was with ribs, all consisting of lobes and furrows along the trunk. We took an increment core from one of the lobes. Presuming the equal increment throughout the trunk, the approximate age of the tree was 222 years. Reconstructing the age graphically, the approximate age of the tree was 235 years (1764 AD). The latter age is more probable, because trunk lobes usually have wide tree-rings and these give smaller age for the tree. The bark method yielded only 190-220 years of age for that tree.

This tree is known as oak of Peter the Great. A legend is told that after participating in a wedding party of a citizen of Tallinn, Peter rested in a garden cabin under this tree (Vende, 1991). This event had to be taken place in the period after falling of Tallinn to Russians in 1710 and before death of Peter the Great in 1725. If the legend is true, the age of the oak should be well over 300 years. Our result points that the oak is younger and the story about Peter the Great is just a legend. It is still possible that the oak has grown remarkably narrower tree-rings in his young age and its age is greater than calculated from the tree-rings in the trunk lobe.

A nice oak grows in Falk Park (No. 19). Presuming the same increment rate through the trunk, age of 148 years was found for the tree. The tree can be still a few years younger, with age ca 145 years. As the core covered most of the radius, it is a rather probable age. It means the zero-year 1854 AD. The age yielded from the bark was 144 years. In this case the age estimations from tree rings and bark layers coincide finely.

It is known that Hans Heinrich Falck (1791-1874) started to establish the park in his property here in 1857. A pond was levelled, the ground was surrounded by fence, trees and shrubs were planted and pathways made. The park was ready probably in 1860. The approximate age of the oak fits well with the known age of the park. It means that H. H. Falck planted the tree as a young oak of more than 1.2 m high between 1857 and 1860 AD. On a map of Tallinn by Franz Kluge in 1856 one can see that the area was turned into park for that time already: there is a pond surrounded by trees and walkways with trees. So it is possible that the oak was planted some years earlier already.

Two oak trees behind the house Adamson St. 2B are of comparable thickness with each other (No. 20, 21). Assuming the same average ring width through the radius, age of the trees was calculated as 194 and 193 years. Presuming wider tree-rings in the inner part of the radius, the approximate age was found as 190 years for both trees. It means the zero-year is ca 1809 AD. For the southward tree the bark method gave bigger age than tree rings - 230-250 years. The age determination showed that these two oaks are contemporary, they were planted at the same time, both soon after 1810 AD. There are no written references known to these oaks, but their age coincides with the known origin of settlement of that area. A map of 1856 shows that in the first half of the 19th century that area was settled by gardens of the townspeople and there were only a few buildings then (Reval, 1856).

An oak tree thought to be Mayer's oak at Harjumägi Park was chosen for age sampling. Assuming the same average growth rate throughout the age of the tree, its age was calculated as 159 years. Presuming wider tree-rings in the inner 31 mm of radius, the proposed age of the tree would be ca 150 years (zero-year 1849 AD). According to the bark method, age of this tree was 145 years.

Bürgermeister C. Mayer arranged the hill of Harjumägi in Tallinn in the autumn of 1861. In the course of these works four members of the Promenade Commission of the town planted an oak on Harjumägi hill in 1862. Twenty-five years later, in 1887, a plaque for C. Mayer was set before the tree (Vende, 1991; Sander, 1998). To identify the nowadays oak as the Mayer's oak, we have to allow that the tree planted by the high Commission in 1862 had grown 13 years after reaching its sampling height, 1.2 m. The conclusion is that it was used to plant quite tall trees in the last century.

Discussion

The age determination methods of big trees used here were new and not used before in Estonia. The method of determining tree age by its tree rings was developed from simple ring counting to extrapolation of increment rate to the inner part of tree-trunk what was out of reach of age corer or if the tree-trunk was hollow inside, without tree rings preserved. As any extrapolation, assessment of number of missing rings depends on assumptions. It seemed logical to use increment of younger oaks as a model for growth rate of the thick hollow oaks. It appeared that cumulative increment curves of younger oak trees differ remarkably from each other. Such variety of growth rates is characteristic of trees growing in forest stand, where every tree specimen has its different position in competition with other trees, or to trees grown up between big tree specimens in an old park. So it was reasonable to fit the cumulative increment curve of each thick oak with that of the younger oak trees. The most smoothly joining curve was taken as a probable model for the older oak tree. The fact that the big oaks often had different growth models for their youth period enables us to conclude that many of these trees were probably also grown up in a natural forest stand rather than in a young park. This conclusion regards especially big oaks of the Kadriorg Park, where there was apparently oak forest before establishment of the park in 1718.

The bark method of age determination of oaks was not used before, because it was commonly considered that oak bark does not contain distinct annual growth layers. Widely accepted textbooks of plant anatomy state that many woody dicotyledons, incl. *Quercus* and *Tilia*, have nonstratified phloem (e. g., Esau, 1953:294; Эзау, 1980:184). In some issues (Esau, 1964, Fig. 4 & 5, *Quercus rubra* L.; Braun et al., 1982, Fig. 113, *Quercus robur* L.) microphotographs of phloem still show that there do exist bands of fibres and sclereids in the oak bark. The general opinion is that the annual borders of phloem zones in the bark of trees are often difficult to identify (Trendelenburg, Mayer-Wegelin, 1955; Schweingruber, 1996).

We met the challenge to prove the opposite view. Determination of age of oaks by tree rings and bark layers has demonstrated coinciding results in most cases. In certain cases, if wood core of an oak contained too little tree rings, age of the tree was more exactly determined by bark layers. For tree species as common oak (*Quercus robur* L.) with long preserving bark, age determination methods by wood and bark layers can be considered as supplementary. For other tree species with dropping bark or with non-distinguishable annual layers in the bark, tree ring method remains the only one for age determination.

Comparison of age assessment by tree rings and by bark method is given in Table 4. In this table the age means the approximate number of years since the tree reached the sample height of 1.0...1.3 m to sampling year 1999. We have not added the period for growing up from seed to sampling height, assuming that age since sampling height more or less coincides with tree's age at planting time.

The Table shows that in some cases calculated ages of trees coincide with their age known from written sources. We must consider that reliability of the tree ring method depends on the length of part of radius which content of tree rings has to be found. Reliability of the bark method depends on the degree of weathering of the bark sample. For these reasons in some cases the bark method yields more reliable result and in some cases the tree ring method does. In certain cases - for oaks No. 5, 7, 8, 11, 14, 17, 19 - the two methods give quite coinciding results. We have to assess which method is more reliable in a certain case, due either to relatively longer tree ring core or more complete bark sample. For trees No. 3, 9 and 22 only the bark method has produced a result coinciding with written data about the origin of the tree. For trees No. 18 and 21 only the tree ring method gave an age which coincided with the known age of the trees. Oaks No. 1, 7 and 15 are evidently older than the park or cemetery at the place, whereas oak

Table 4. Age of oaks (rounded to decades) in 1999 calculated both from tree rings and by bark method

Tree (sample) No.	Location in Tallinn	Perimeter of trunk, cm	Age by tree rings (onset years AD)	Age by bark method (onset years AD)	Known establishment of stand	Agreement with references
1	Weizenbergi 26	520	360-390 (1610-1640)	310-330 (1670-1690)	1718	Tree is older
3	Weizenbergi 26	214	260 (1740)	260-280 (1720-1740)	1718	Bark age agrees
4	Weizenbergi 26	339	260 (1740)	310-320 (1680-1690)	1718	Tree is older
5	Weizenbergi 26	388	280-330 (1670-1720)	280-300 (1700-1720)	1718	Both methods agree
7	Park of Kadriorg	352	300-330 (1670-1700)	310-330 (1670-1690)	1718	Tree is older
8	Park of Kadriorg	272	260-310 (1690-1740)	270-290 (1710-1730)	1718	Both methods agree
9	Park of Kadriorg	505	300-330 (1670-1700)	260-280 (1720-1740)	1718	Bark age agrees
11	Park of Kadriorg	384	260-320 (1680-1740)	270-290 (1710-1730)	1718	Both methods agree
12	Kopli distr., loop of rails	507	310-340 (1660-1690)	210-230 (1770-1790)	Afforestation since 1611	Disagreement
13	Ship Repair Factory	474	300-360 (1640-1700)	250-280 (1720-1750)	Afforestation since 1611	Disagreement
14	Kaluri 2	405	270-340 (1660-1730)	270-300 (1700-1730)	Afforestation since 1611	Tree is younger
15	Former cemetery	410	310-360 (1640-1690)	370 (1630)	Established 1774	Tree is older

No. 14 has started much later than the onset of afforestation of the area. For some oaks (No. 4, 12, 13) tree ring method and bark method yielded different age estimations. Although bark age of oak No. 4 is closer to the known establishment year of the park, it is most probable that the tree originates from the pre-park period already. For oak No. 12, tree ring content of half of the radius had to be assessed and therefore age assessment by bark layers has to be considered more reliable in this case. The same argument is true for oak No 13.

Conclusions

Age determination methods of big oaks by using cumulative increment curves of wood and bark method have shown their feasibility. We have cored twenty two big oak trees growing in Tallinn, each by one core extracted at breast height. The perimeter of trunk and thickness of bark of the oaks was measured. Probable age of these big and often hollow oaks was first estimated by using average ring widths in the core. These estimations were corrected applying cumulative increment curves of younger oaks to fill the radius gap of thick oaks and by smooth prolongation of the measured growth curve to the time axis. Simultaneously bark method by Mart Rohtla was applied to assess the age of the oak trees. We can conclude that these two methods - assessing age of oaks based on wood increment and on bark increment - act as supplementary to each other. Generally their results coincide quite well. Reliability of the tree ring method depends on the ratio of the length of the core to the rest of the radius. Reliability of the bark method depends on the degree of weathering of the bark sample. In some cases, if the oak trunk is considerably decayed, the bark method is the only reliable method of age assessment of the tree. In the case of trees (and tree species) with weathered bark the tree ring method is the only appreciable age assessing method. The results were compared with known historical data. In most cases the estimated age of big oaks appeared to be in accordance with known or assumed planting time of the trees.

The thickest living oak tree in Tallinn was found at Weizenberg St. 26 in the Park of Kadriorg, with trunk perimeter 520 cm at breast height. The same oak is also one of the oldest, with probable age about 360 years (onset in about 1640 AD). There were nine more trees among the sampled oaks with their probable age about three hundred years.

In the course of further collecting more tree ring samples from younger oaks the method of assessment of oak age by cumulative radial increment curve can be refined to get more reliable results about the age of thick trees. Also the recently introduced bark method of age determination of oaks needs to be refined and checked by tree ring method.

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ВОЗРАСТ БОЛЬШИХ ДУБОВ В ТАЛЛИННЕ, ЭСТОНИЯ

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Резюме

В Таллинне большие экземпляры дубов растут в основном в трех районах города: в парке Кадриорг, в Копли и в центре города. Возраст двадцати одного дуба больших размеров был определен разными методами: графически по радиальному приросту древесины (экстраполяцией прироста в керне в остальную часть радиуса) и методом корки, введенным М. Рохтла. Полученные возрасты деревьев были сопоставлены с известными письменными данными об истории данных участков.

Было установлено, что многие дубы являются старше парков или землевладении своего нынешнего нахождения. В популярном парке Кадриорг (создан в 1718 г.) до сих пор растут дубы, которые произрастали уже до заложения этого парка. Возраст их превышает 300 лет. Наиболее толстый и старший дуб в Таллинне тоже был найден в парке Кадриорг; обхват его ствола 520 см на высоте груди и возраст около 360 лет (время возникновения ок. 1640 г.).

Графический метод определения возраста и также метод корки М. Рохтла требуют дальнейшего совершенствования и проверки на новом материале.

Ключевые слова: возраст дубов, годичные кольца, метод корки, Таллинн