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Review paper

A history of varying methods for determining tree age in Estonia with emphasis on oak

Heldur Sander

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Abstract. This paper explores the history of age detection of trees, especially the age history of oak trees, throughout two centuries in Estonia. It was already in the beginning of the 19th century when relations between the size and age of oaks in northern Latvia (previous Livonian province) were described. The paper explains how the species concept of *Quercus robur* developed over time in the past and points out discussions on the existence of two varieties *Q. robur* L. var. *tardiflora* Czern and *Q. robur* L. var. *praecox* Czern. It also states that thanks to the use of the increment borer, the first dendrochronological studies were carried out in Estonia in the 1920s. Dendrochronological research in the Soviet Union began in the 1950s with Lithuania being the leading country in the field headed by Teodaras Bitvinskas. In Estonia, research was continued in the 1960s until now. The paper takes a look at the life of Mart Rohtla who introduced the method of determining tree age according to tree bark, presents his standpoints on oaks and critically assesses these. A comparative assessment is given on the ages of oak and lime trees found according to the tree-ring method and bark increment method. The great ages of the oaks and limes found by applying the bark increments method are doubted and considered unreliable. However, the age of the surface layers of the bark of oaks and limes needs clarification in the future.

Key words: dendrochronology, Mart Rohtla, crop of trees, *Quercus robur, Tilia* sp.

Author's address: Retired scientist, MSc in geoecology, Mahtra 9–121, Tallinn, Estonia; e-mail: heldsander@gmail.com, tel. + 372 53340399

Introduction

The modern dendrochronological trend in science is rather diverse in its approaches and attempts at establishing correlations (Fritts, 1976; Schweingruber, 1988; Speer, 2010). However, every country has experienced a different dendrochronological trend within the past 150 years during which the 1860s played an important part. The contemporary trend was started by German forest researcher Maximilian Robert Pressler (Preßler) who worked as professor of mathematics at the Royal Saxon Academy of Forestry (Königliche-Sächsische Forstakademie) in Tharandt near Dresden. He used a hollow borer for measuring tree increment, put in into practice and implemented his method for silvicultural measurements along with mathematical analysis (Pressler, 1868). Pressler's forest research ideas reached Russia as well as

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the Baltic provinces which were part of the German culture and research realm. The latter was thanks to the sons of local manor owners and officials studying in Tharandt (Schuster *et al.*, 1998). Therefore, Pressler's monograph of 1868 was soon briefly introduced to local forest owners and people interested in science (Anonymous, 1870).

In the then Russia (now Ukraine), the modern trend was started by Feodor N. Shvedov (1892a; 1892b; 1972), physics professor at Odessa University, who within 10 years determined the recurrence of droughts according to the tree ring width of the North American species of *Robinia pseudoacacia* L. This is considered as the first dendroclimatological research in the world, showing also that trees can act as indicators of precipitation in the absence of meteorological data. It is equally noteworthy that the tree species turned out to be a North American species introduced in Europe which had been grown here for more than 250 years. This clearly demonstrates how some foreign species may be better suited as climate indicators than domestic species of a specific region.

The Pressler borer was used in South Estonia in the 1920s by forest researcher Paul Reim. Paul was the forest guard of a district where the so-called Long spruce (*Picea abies* (L.) H. Karst) was growing close to a meadow named Long-spruce ("Pikakuuse"). The spruce (height (H) = 33.5–34 m, diameter at breast height (DBH) = 100 cm) increment of the preceding 10 years (within 0.8 cm) was measured using the Pressler borer according to which the tree was believed to be more than 200 years old (Reim, 1924).

In the former Soviet Union, the aforementioned research trend was pursued with consistency beginning from the 1950s. Of the Baltic States, Lithuania rose to the forefront in dendrochronology, with Teodoras Bitvinskas as the leading researcher (Bitvinskas, 1968; Anonymous, 2019). One of the milestones to sum up the previous research and set trends for the future was the 1968 conference in Vilnius (Kairiūkštis, 1968). It was attended by scientists from many parts of the former Soviet Union. Estonian biologist Jüri Martin of the Ural Branch of the Institute of Plant and Animal Ecology of the Academy of Sciences of the USSR in Sverdlovsk (now Yekaterinburg) delivered a presentation there. A 1964 graduate from the University of Tartu, he was continuing his graduate studies in Sverdlovsk and had already defended his dissertation there (Martin, 1967; Martin, 1968).

In Estonia, the dendrochronological trend in researching live trees and stands took shape in the 1960s. In the second half of the decade, the method was used by forest researcher Elmar Kaar to study a stand on the Puhtu peninsula, West Estonia. An increment borer was used to date the oldest elm (*Ulmus glabra* Huds.) at 512 years, a pine (*Pinus sylvestris* L.) at 230 years and a horse chestnut (*Aesculus hippocastanum* L.) at 240 years. The oldest oak tree was found to be approximately 600 years old; the dating method, however, was not provided (Kaar & Kalda, 1970). Subsequently, using a 50-cm-long borer, the age of what seems to be the same tree (H = 24 m, DBH = 153 cm, 2000) was established at 370 years (Relve, 2003).

In the village of Pühajärve, parish of Otepää, South Estonia, the dendrochronological method was used in 1967 to date the Oak of War of Pühajärve (H = 20 m; DBH = 210 cm, 1967) at approximately 380 years (Rebane, 1968). In the village of Vetepere, parish of Albu, Järva County, it appeared that the oak of Tammsaare (Vetepere) (H = 16 m, DBH = 100 cm, 1969?) had sprouted in about 1820 (Rebane, 1969). In either case, the increment was measured in relation to the points of compass. The case of the Oak of War of Pühajärve showed that if we postulated the increment towards the east at 100, then the increment towards the west would be 50.9, towards the south 95.3 and towards the north 61.2. With regard to the Tammsaare oak, it appeared that if the increment was posited at 100 towards the west, then the increment towards the east would be 88.3, towards the south 96.1 and towards the north 75.2. The crown of the tree reached 7 m towards the east and the south, 8 m towards the north and barely 6 m towards the west, the direction of the greatest radial increment (Rebane, 1968, 1969). Stem increment, however, is proportional not so much to annual ring width as to annual ring cross-section area (Shvedov, 1972).

The dendrochronological research trend also galvanised a professor of the University of Tartu, Viktor Masing, whose many scientific interests included old trees and their age on a global scale (Läänelaid & Sander, 2002). Of his students, Alar Läänelaid (1976; 1999) came to be a developer of the trend (Sander, 2011). At present, the trend is pursued at the University of Tartu and the Estonian University of Life Sciences.

A novel approach to tree dating research in Estonia in the 1990s was adopted by Mart Rohtla who developed a dating method based on the outer bark of the trees. As is known, bark (outer bark) thickness varies across tree species, on different sides of the stem and at different heights. Herein, we will not delve into the essence of the outer bark of trees or into the abundant researches on the respective relationships. The reader is, however, referred to two articles in this regard (Rosell *et al.*, 2014; Morris & Jensen, 2017), which provide a fairly good coverage of the issues surrounding the subject of the outer bark.

Next, we will introduce M. Rohtla and his method devised in the 1990s based on his own Estonian-language article (Rohtla, 1998). The purport of this article is to find researchers who might take interest in the approach, draw inspiration from it and refute the previous positions or envision some practical applications and new opportunities. The past findings have, in essence, been published before (Läänelaid *et al.*, 2001; Läänelaid & Sander, 2004; Sander *et al.*, 2008).

The topic of this paper is based on historical approach to determining tree age in Baltic provinces. This gives us the perfect reason to introduce the work of Andreas von Löwis of Menar (1777–1839), a remarkable forest researcher who was ahead of his time. His primary focus on oak trees (*Quercus robur* L.) probably sparked an interest in Mart Rohtla several years later in the representation of this species. The main purpose of this paper is to compare the method of Estonian tree bark age to dendrochronological studies and critically analyse the method.

Historical origins

The climate-imposed habitat limits, growth and stem thickness correlations of oaks (*Quercus robur*) as evidenced in the provinces of Estonia and Livonia (now the Republic of Estonia and North Latvia) were analysed by A. von Löwis of Menar (Löwis, 1813; Löwis, 1824). He was born at Vanamõisa (Wannamois) Manor, West Estonia, studied in the universities of Jena (beginning in 1801) and Heidelberg (beginning in 1803) and at Schwetzingen Forest Institute (Forstinstitute zur Schwetzingen) in 1806–1808. A. v. Löwis returned to his homeland in 1808 and worked as Secretary of the Livonian Public Welfare and Economic Society (Livländische Gemeinnützige und Ökonomische Sozietät) in 1811–1839 (Recke & Napiersky, 1831; Blum, 1846; Lenz, 1970).

According to A. von Löwis (1813; 1824), oaks (Stieleiche – *Quercus pedunculata* Ehrh.) standing on a good soil grow so rapidly until 100 years of age that the width of the annual rings is often ~3.4 mm (1½ pariser Linie). Up to approximately 300 years of age, oaks in favourable conditions produce annual rings with a maximum with of ~2.3 mm (1 par. Linie). Until 500 years of age, however, annual rings show a brisk increment of ~1.5 mm (2/3 par. Linie) on average, and in later centuries, as long as there is any increment at all, one can find annual rings with an interval of more than ~2.3 mm. The outer annual rings of very old trees become increasingly dense and are finally so thin as to render counting almost impossible. Often, the widths of 10 annual rings come close to ~2.3 mm. Oaks more than 500 years old have average annual ring widths of ~0.8 mm (1/3 par. Linie), and therefore their age is underestimated rather than overestimated. Taking the above into account, A. von Löwis (1824) established the following principles (Table 1).

Table 1. The relation between breast height and age of oaks.

No	Diameter at breast height of oaks		Age of trees in years
	Russian feet (0.3048 m)	cm	
1	6 1/2	198	100
2	10 5/6	330	200
3	15 1/4	465	300
4	18 1/8	552	400
5	21	640	500
6	22 1/2	686	600
7	24	732	700
8	27	823	900
9	28 1/2	869	1000

A. von Löwis added that the estimation was based on experiments performed in inland Livonia and was thus only applicable to those particular areas. As the growth of oaks in the province of Estonia was somewhat slower, the trees were not to be dated based on the said rule. By inland Livonia, A. v. Löwis apparently meant the present-day North Latvia. His presumed residence, Nurmu (Nurmis) Manor (Recke & Napiersky, 1831; Lenz, 1970), was located there. When the readers here were introduced to an oak with a circumference of 45 feet (13.72 m) growing in Pisterwald (Pister-Wald), Bohemia (Königreich Böhmen, the Czech Republic) (Röchy, 1815), A. von Löwis reported that the largest oak was growing at Vecate Manor (Alt-Ottenhof) in the parish of Mazsalaca (Kirchspiel Salisburg). The oak there (Ottenhof nach Salisburg) was 19½ feet in breast height circumference (594 cm). At its root, the tree was upwards of 5.5 times thicker, its thickness being enormous (über die Wurtzel mehr als 5 1/2mal so stark als jene, eine wirklich ganz ungeheure Stärke) (Löwis, 1815). Among the 17 largest oaks, with their circumference ranging between 12–29 feet, eight specimens situated on the territory of the present-day Latvia were thicker than the aforementioned one. The stoutest oak – 29 feet (884 cm) – was growing at the then Karlsruhe Manor outside Cēsis (bei Karlsruh unweit Wenden), beside the Riga road (Löwis, 1824), apparently within the precincts of what is currently known as Kārļamuiža (Pētersone & Stepiņš, 2019).

Of the two thickest oaks in Estonia, one stood at Rannaküla on Saaremaa Island, its circumference being 23 feet (701 cm), and the other, of 21 feet (640 cm), at Ranna (Tellerhof) Manor by Lake Peipsi, East Estonia (Löwis, 1824).

This was followed by an approximately 150-year hiatus in any substantive studies of the sort in this region.

The life of Mart Rohtla (1933–2017) and his views on oaks

M. Rohtla (b. Ringenberg) was born in the village of Ore (Oore) in the parish of Tori, Pärnu County, on 9 November 1933 (Sander, 2017). The annexation of the Republic of Estonia by the Soviet Union in 1940 resulted in great affliction for the family, as Mart's father Karl Rohtla (Ringenberg, 1904–1945) was deported in 1941 and died in a prison camp. A son of "an enemy of the people", as the conception was back then, Mart Rohtla was convinced he would hardly be admitted to the University of Tartu and went to study at Leningrad (now St. Petersburg) State University instead. After graduating from the university in 1961, he transferred to the then Institute of Cybernetics of the Academy of Sciences, which was opened a year before (1960–2016). From 1968 right up to his retirement in 2007, M. Rohtla worked as senior researcher at the institute's Laboratory of Phonetics and Speech Technology. At the institute, M. Rohtla involved himself in the research trends of speech and speaker identification and speech synthesis and analysis, with his innovative ideas finding application in the development of the corresponding devices. Mart was known at the institute as an individual with ideas that were often considered unexpected and unusual. Throughout his years at the institute, he was regarded as one of the brightest personalities who was never short of wise words, ideas and inspiration to a number of colleagues.

In addition to his vocational and scientific work, M. Rohtla took interest, among other subjects, in dating old trees and climatic relationships. In the introduction to an article on the study of the outer bark of oaks, M. Rohtla (1998) presents, without references, his positions. He claims that the circumferences of same-age oaks (*Quercus robur*) differ up to eightfold depending on their site conditions: the circumference of a hundred-year-old oak growing in a poor soil hardly reaches half a meter while that of its coeval counterpart in a farmyard may exceed four metres. An oak four meters in thickness may be one hundred, two hundred, three hundred or even eight hundred years old. The slower the growth rate of the tree, the more valuable its timber in our ancestors' eyes. Marcescent oaks (*Quercus robur* L. var. *tardiflora* Czern) were felled for their dense texture. The briskly growing 'summer oaks' (Rohtla: 'crap oaks') were far more inferior in the eyes of ship, horse-cart, sledge and barrel manufacturers.

In M. Rohla's view, most of our bulky oaks are growing on good soil and, despite their dimensions, are relatively young. According to him, 'summer oaks' often contract fungal diseases and die at a few hundred years of age. In rare cases, however, they hollow out as a result of a wildfire. The fire destroys the fungus and enables air circulation in the tree cavity. The oaks' archenemy – the fungus – dies, and the trees' hopes for life are renewed. If such a tree is not immediately felled by storms, its outer layer thickens with every passing year, and its viability increases. The majority of our large trees are hollow, which renders their dating by the increment borer problematic. Therefore, other methods must be found to determine the age of live old trees.

A comment on Mart Rohtla's views of the past

The dependence of oak thickness on site properties has, in Estonian circumstances, to do with the groundwater level, topsoil properties and thickness, differences between areas with Silurian and Devonian substrata, soil properties and moisture regime (Kaar, 1964). The past researches, however, are inadequate to corroborate that the circumferences of same-age oaks differ eightfold depending on their site, or that the ages of oaks four metres in circumference vary within the aforementioned range.

The oaks in this region have been classified according to August Wilhelm Hupel (Löwis, 1813), as *Quercus robur* and *Q. foemina* Mill. The reference by A. von Löwis to Issue 17 (published in 1788) of A.W. Hupel's serial Nordic Miscellany (Nordische Miscellaneen), however, proved incorrect. Later, the oaks were considered to be *Quercus robur* (in German Die Stein- oder Wintereiche) and *Q. pedunculata* (Die Steil- oder Sommereiche) (Löwis, 1813; Löwis, 1824). The first was to designate *Quercus sessiliflora* (Q. *petraea* (Matt.) Liebl., 1784), which does not grow naturally in Estonia and Latvia. The habitats of either species were presented as similar (Habitat in Europae nemoribus) (Willdenow, 1805), thus they were not clear back then. Later, reference was made (Löwis, 1824) to the concept of the German naturalist Johann Matthäus Bechstein (1821). Such an approach was due to the taxonomic confusion concerning European oaks and to the divergent acceptance of species designations (Willdenow, 1805; Rees, 1819).

According to dendrologist Karl Aun (1927; 1929), the botanical designation of the oak of our forests is *Quercus pedunculata*. Its leaves have a very short stalk and a cordate base, and its acorns have a long, 3–6-cm stem. The tree sheds its leaves in the autumn and rests bare in winter. However, some specimens were occasionally found that retained their withered yellowish-brown leaves through the winter. This was observed in oak alleys in the city of Pärnu, where an occasional tree had not shed its old leaves. No differences were noted in the outward appearance of oaks with or without foliage in winter, their acorns and acorn stems being identical. Nevertheless, a significant biological difference between the two species was perceived. In the spring of 1925, the oaks with overwinter leaves in Pärnu foliated 3–4 weeks later than those without leaves in winter. On 3 June 1925, the marcescent oaks started to bloom but had no new leaves, whereas the other oaks already had young shoots 6–7-inches (15–17 cm) long and had advanced well beyond blooming time. In our climate, late spring night frosts are often detrimental to oak increment, hence young oaks were nursed under the cover of other trees. For oaks with overwinter foliage and a month's delay in spring foliation, however, the impact of belated night frosts was insignificant. Reportedly, they were identified by Tschernyayev in Ukraine in 1858 as *Quercus tardiflora*. The same oak species was also found in Estonia. It must be designated *Quercus pedunculata tardiflora* Tschernyayev and should have particular importance in our climate (Aun, 1927; Aun, 1929). Individual oaks with early or late blossoming were nothing out of the ordinary, such specimens were registered within both of the species (*Quercus pedunculata* Willd. (Stieleiche) and *Q. robur* Willd. (Traubeneich) in Germany (Bechstein, 1821).

According to the forest inspector of Pärnu district Arthur Hermann Rühl, the share of 'winter oaks' in Pärnu County, West Estonia, was 20%. Furthermore, the learned agronomist Ruubel had reported that the rural people of Viljandi County were good at telling 'winter oaks' from 'summer oaks' (Nenjukov, 1931). Theodor Nenjukov also presented the distinguishing indicators between 'summer' and 'winter' oaks. The crown of *Quercus pedunculata* Ehrh. var. *praecox* Czern. was told to be wide and sprawling, with its leaves foliating 3–4 weeks earlier, thus falling within the belated spring frosts period. The acorns of the oak were large and its timber bluish yellow. The share of mechanical tissue was 80%. The crown of *Q. pedunculata* Ehrh. var. *tardiflora* Czern. was, however, compressed and upward, with its leaves foliating 3–4 weeks later, thus passing the belated spring frosts period. The acorns of the oak were small and its timber light yellow and hard. The share of mechanical tissue was 90%. Apparently, K. Aun and T. Nenjukov were familiar with the work of the famous Ukrainian naturalist and long-time university professor Harkov Vassili Matveyevich Tschernyaev (also Basil Matveyevich Czernyaev and other name forms), where the two aforementioned oak varieties were specified (Chernyaev, 1858; Prokudin, 1953). The properties of the two oak varieties have been republished, as well as subjected to genetic scrutiny (Chokheli *et al.*, 2016).

K. Aun (1932) responds to T. Nenjukov by asking why these oaks were called 'winter oaks' (Wintereiche), as the latter designation was used on our part to denote *Quercus sessiliflora* Sm. Apparently, *Q. petraea* (Matt.) Liebl. was confused with *Q.*

pedunculata Ehrh. var. *tardiflora* Czern. The reason was that the specimens of *Q. petraea* foliate in Estonia 10–14 days later than those of *Q. robur* and retain their leaves all through the winter. Marcescent *Q. robur* trees ('iron oaks'), however, were regarded as a variant in Estonia (Mathiesen, 1934). Andres Mathiesen, professor of silviculture at the University of Tartu was, in fact, fascinated with the phenological variants of oaks. This is why he ordered the forest officer of Järvselja Training and Experimental Centre in his letter of 2 February 1936 to have the forest guard of Rõkka district mark the oaks growing beside roads which retain their leaves until spring. In spring, the task was to observe whether these oaks bud concurrently with other oaks or later (Kasesalu, 2000).

If viewed only as a phenological variant, they are common over a very extensive territory. The overall variation within the species, however, is somewhat more complicated (Mamaev, 1968). In the Estonian language, the distinctions have persisted to the present day: 'talitamm' (winter oak), 'raudtamm' (iron oak) or 'lesetamm' (widower or widow oak), i.e. *Quercus robur* L. var. *tardiflora* Czern., and 'suvitamm' (summer oak), i.e. *Q. robur* L. var. *praecox* Czern. (Plant database, 2019). It has also been alleged that the inhabitants of the island of Saaremaa, West Estonia, made a strict distinction between oaks by their site. Oaks growing on a sandy soil were fragile and red on the inside while those growing on a clayey one were blue and hard as iron (Viires, 2000).

M. Rohtla's claim that 'summer oaks' of a few hundred years of age frequently contract fungal diseases and die seems to be true, because the opposite is correct for 'winter oaks' (Chokheli *et al.*, 2016): "*Q. robur var. tardiflora* is less defeated by pests and diseases." The two varieties have also demonstrated different resistance to winter moth (*Operophera* brumata L.) damage (Andrushchenko & Koval, 2014).

Mart Rohla's outer bark dating method

While annual rings are clearly observable and measurable in heartwood, the increment markers in outer bark are not visible to the naked eye. However, when discs of dried outer bark are well sandpapered and placed under a microscope (a magnifying glass is of some help, too), the annual markers are clearly identifiable already at tenfold magnification (Figures 1–3). The photos show that unlike annual rings in heartwood, the clearly traceable lines in the outer bark are discontinuous. The image is reminiscent of a movie theatre with rows of chairs and aisles in between: the closer to the screen the smaller the number of chairs in a row. In an outer bark disc, the rows of "chairs" mark annual increments and the "aisles" the radial channels. Every year a tree grows by one annual ring (a). Depending on the site, the soil and the climate, the width of the annual rings of oak and lime ranges from one to ten millimetres. Along with the heartwood, the outer bark, of course, also gains in thickness: in oak by 0.2–0.8 mm and in lime by 0.1–0.4 mm per year. The annual increment (b) of the outer bark of briskly growing trees is approximately four times that of trees growing in a poorer environment. Thus, the thickness of the outer bark correlates to tree age twice as strongly as the thickness of the stem. An analysis of the discs of sandpapered outer bark and the annual rings of a tree showed that there is dependence between the outer bark annual increment (b) and the stem annual increment (a), as follows:

$$b = ka$$

It is 0.131 in oak and 0.107 in lime. Thus, the outer bark thickness of a tree (l)

$$l = nb = kn\sqrt{a}$$

and the perimeter of the tree (p)

$$p = 2\pi an+kna$$

where n is the number of annual rings to be determined. For solving the equation system in relation to tree age, we find

$$n = 2\pi l2k2p-2\pi l$$

Since $p >> 2\pi l$, then

$$n = 2\pi l2k2p$$

By replacing the coefficient (k) with its values and adding to the result obtained the years of tree growth to the height from which we took the outer bark samples, we get

$$n_{oak} \sim 0.365l2p+5h$$

$$n_{lime} \sim 0.550l2p+5h$$

where n = tree age in years, p = tree perimeter in metres, l = outer bark thickness in millimetres, h = the height from the ground of the point used for determining tree perimeter and outer bark thickness in metres.

Figure 1. A sandpapered disc of lime outer bark (magnification approximately 15 times). The horizontal discontinuous rows mark the annual increments of the outer bark. Radial channels run through the discontinuation points. The radial channels are almost parallel near the bottom of the outer bark but converge at the top. The point of convergence of the radial channels marks the beginning of the outer bark growth. If the crest (top) of the outer bark is missing, the radial channels do not converge on the image plane (Rohtla, 1998).

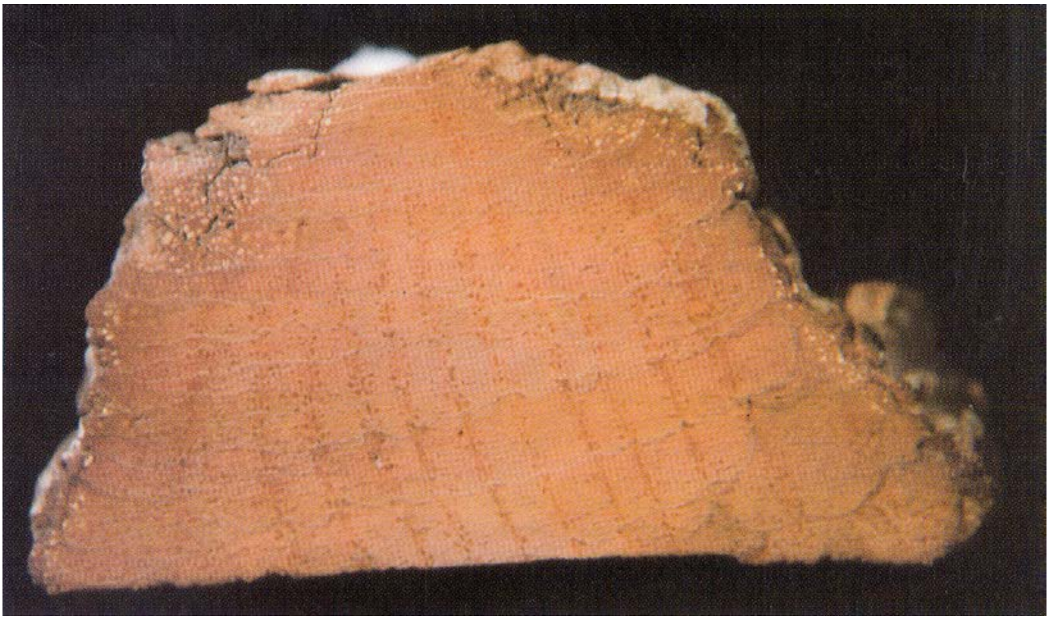

Figure 2. An approximately two-fold magnified image of a sandpapered disc of the outer bark of an oak (Rohtla, 1998).

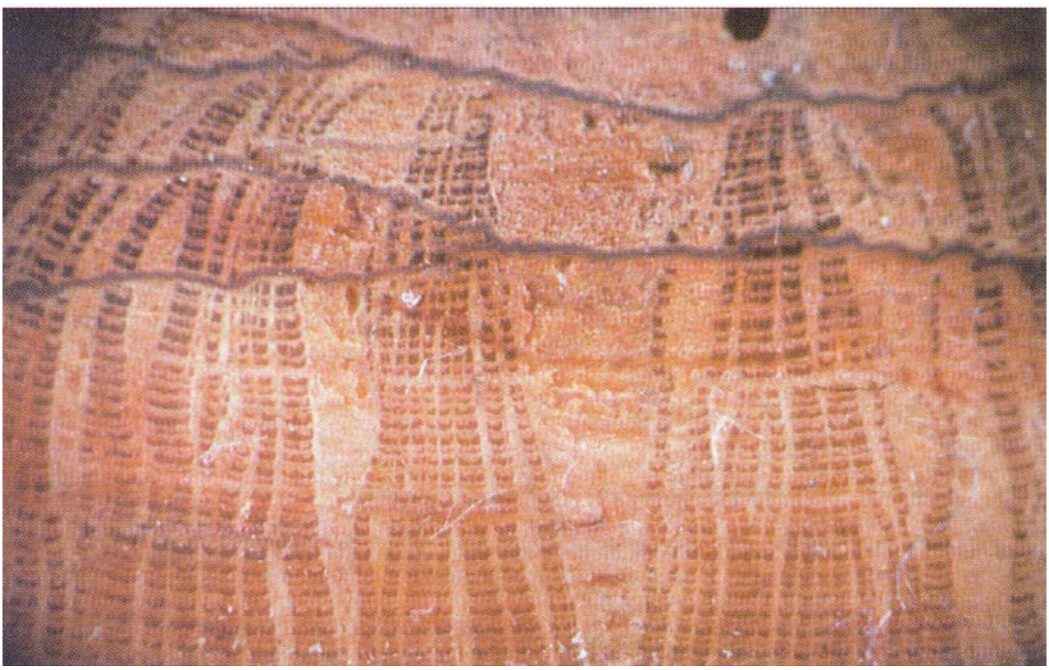

Figure 3. An image of a sandpapered disc of the outer bark of an oak, magnified 30–35 times (Rohtla, 1998).

Since in the case of old trees the height h has a relatively insignificant bearing on the result, it is practical in the last equations to leave out the added 5h. Hence, we may say that tree age is approximately proportional to outer bark thickness squared and inversely proportional to tree perimeter. This correlation enables the dating of oak and lime with a 20% precision.

In order to achieve higher precision, the annual rows in a well-preserved fragment of the outer bark must be counted. For that purpose, a dried piece of the outer bark is to be sawn into disks and sandpapered until they are clearly visible. The annual rows in outer bark are very narrow, hence they can be precisely counted only under a microscope. Over many years, the outer bark in the lower part of old trees suffers a lot of damage. The crests of outer bark wrinkles are clearly worn and have acquired a trapezoid form. Well-preserved outer bark wrinkles have sharp crests; a sample shall be taken at a point where the wrinkle crest is as high or slightly higher than the neighbouring crests. In the microscope image, the radial channels in a well-preserved piece of outer bark converge at a certain point on the crest. This is sufficient proof that the crest dates back to the tree's adolescence. If we take a sample of outer bark from a worn or dried side of the tree, we establish fewer years for the age of the tree than in reality. Outer bark thickness is measured in millimetres and stem circumference in metres with a 0.05 m precision. Tree circumference, which normally is measured at the height of 1.3 m from the ground, shall now be determined at the same height where the piece of outer bark was extracted or measured.

Oak dating by two methods and a critical assessment

M. Rohtla's tree ages were obtained by measurement. What the outer bark annual rows are is an issue in its own right. The principal comparative material in this regard is a dendrochronological study performed in Tallinn in 1999 on oaks and an occasional lime using the increment borer and the outer bark (Table 2).

Table 2. 22 oaks from Tallinn in 1999 the ages of which were determined graphically with a dendrochronological method; in 17 cases, tree age was determined according to bark (Läänelaid *et al.*, 2001; Sander *et al.*, 2008, updated). Oaks no. 3 and 12 had eccentric stems. Nos. 1–10 were situated in Kadriorg Park, 11–17 in the city centre and 18–21 on Kopli Peninsula.

Sample No., direction and height in trunk, m	Trunk circumference at 1.3 m, mm	Bark thickness, mm	Trunk radius without bark, mm	Length of raw wood core, mm	% of radius without bark	Number of tree rings in the core	Average annual increment, mm	Age graphically/ based on average, years	Age determined using the outer bark method
1 W, 1.3	5200	74	754	324	43	198	1801–1999, 1.6	370/471	290
2 W, 1.3	3530	63	499	348	69.7	195	1804–1999, 1.8	270/277	-
3 W, 1.3; eccentric trunk	2140	41	300	316	105	244	1755–1999, 1.3	250	270–290/ 280
4 W, 1.3	3390	54	486	353	72.6	196	1803–1999, 1.8	260/270	310–320/ 315
5 W, 1.3	3880	62	556	352	63.3	231	1768–1999, 1.5	340/371	280–290/ 285
6 E, 1.0	3830	60	550	341	62	238	1761–1999, 1.4	350/393	-

Sample No., direction and height in trunk, m	Trunk circum-ference at 1.3 m, mm	Bark thick-ness, mm	Trunk radius without bark, mm	Length of raw wood core, mm	% of radius without bark	Number of tree rings in the core	Average annual increment, mm	Age graphically/ based on average, years	Age determined using the outer bark method
7 NE, 1.0	3520	60	501	360	71.9	264	1735–1999, 1.4	330/358	310–330/ 320
8 ?, 6.5; trunk fallen	2700	63	367	366	99.7	292	1707–1999, 1.25 (1.3)	294/294	270–290/ 280
9 ?, 1.0	2720	63	370	197	53.2	218	1781–1999, 0.9	303/411	-
10 SW, 1.15	5050	60	744	348	46.8	153	1846–1999, 2.3	310/323	260–280/ 270
11 SW, 1.0	3840	60	551	346	62.3	198	1801–1999, 1.7	304/324	270–290/ 280
12 S, 1.2; eccentric trunk	2500	26	372	381	102.4	146	1853–1999, 2.6	146	140–150/ 145
13 S, 1.13	1980	38	277	267	96.4	148	1851–1999, 1.8	151/154	-
14 E, 1.2	4740	65	690	335	48.6	108	1891–1999, 3.1	250/223	190–220/ 205
15 S, 1.2	2630	20	399	339	85	127	1872–1999, 2.7	155/148	137
16 N, 1.25	2680	40	387	359	92.8	180	1819–1999, 2.0	193/194	-
17 W, 1.2	2700	35	395	345	87.3	168	1831–1999, 2.1	193/188	230–250/ 240
18 NW, 1.2	2070	25	305	274	89.8	143	1856–1999, 1.9	152/161	146
19 S, 1.06	5070	62	745	371	49.8	180	1819–1999, 2.1	322/355	210–230/ 220
20 S, 1.36	4740	50	705	367	52.1	184	1815–1999, 2.0	330/353	250–280/ 265
21 SE, 1.25	4050	53	592	286	48.3	172	1827–1999, 1.7	337/348	270–300/ 285
22 S, 1.4	4100	40	613	378	61.7	221	1778–1999, 1.7	320/361	365

This was preceded by a study and condition assessment on a 5-point scale of 784 old trees in Tallinn with a breast height circumference of 300 or more centimetres representing 10 plant genera across 15 land-use categories (10 biotopes). Of these, 13% were oaks (Sander, 1988). This was followed by an extensive study of 1,082 outstanding trees of 236 species and cultivars on 342 sites, complete with an analysis and tree dimensions (Sander, 1998). Thus, the trees selected for the 1999 study had been found based on material gathered in the course of field work. Additional studies were used to ascertain the age structure and species composition of, and rarities among, the trees in Tallinn (Sander *et al.*, 2003).

The ages of the 1999 oaks determined using the dendrochronological method and the outer bark method have been obtained at somewhat different heights (Läänelaid *et al.*, 2001; Sander *et al.*, 2008). In 13 cases, outer bark data have been presented in the form of an age range, which was then averaged, resulting in the obtainment of values equivalent to tree ages determined with the dendrochronological method (Table 2).

In 13 of the 17 oaks studied, the ages determined by the outer bark method were smaller by 1–32% than those determined by the dendrochronological method. A close match (1–5%), however, was observed in the case of four trees, the ages being 146 and 145 (No. 12), 152 and 146 (No. 18), 330 and 320 (No. 7), and 294 and 280 (No. 8) years, respectively. Neither was there a great difference in whether the oak trees were younger or older or whether the top of their outer bark was worn to a lesser or greater extent. In four cases, the opposite was true, the oak ages determined dendrochronologically being smaller by 10–20% than those determined by the outer bark method. At the same time, the outer bark thickness in 17 oak trees ranged from 2.0 to 7.4 cm. This shows that the differences in the tree ages determined by the different methods were fairly great. The historical records, being scanty, provided no clues either.

In the garden owned by George v. Müller (Dietrich, 1865) and, evidently beginning from 1860, by the Tallinn Head Forester Wilhelm Kühnert (1819–1891) (Sander & Meikar, 1994), the age of two coeval planted oaks (nos. 12 and 13 in the table) pointed to a planting time falling within G. v. Müller's era. The trees grow by the wall of a two-storey brick residential house (designed in 1903 by Otto Schott) built in 1904 on a plot severed from the Kühnert garden (Sakala, 2018). Hence, the trees were spared in the building process. The ages (137 and 155) of the oak (No. 15) in Falck's Park founded in the second half of the 19th century (Sander & Meikar, 2015) are historically competent, with the 137 years determined by the outer bark method being more likely to be true. The ages of 138 and 152 years of an oak (No. 18) found in Harjumäe Park have their clues in history. The establishment of the park was commenced in 1861 on the initiative of Bürgermeister (member of the Town Council) Carl August Mayer. In 1862, four members of the city's Promenades Commission planted an oak there in honour of Mayer, with a commemorative plaque installed by it in 1887. A sample obtained with an increment borer manifested 143 years, which shows that the tree, then 1.2 m tall, was planted in 1856. Thus, it is older. In 1999, an oak growing in Virumäe Park was dated, using only the outer bark method on a 32-mm thick sample obtained at the height of 1.5 m, to be 128 years old. To compensate for the worn part, approximately 10 years were added. Because the park was known in the 1870s as merchant J. E. Steinberg's garden, the oak may have been his property.

In the outer bark samples from two oaks (DBH = 91 cm, DBH = 134 cm) in Trummi Street, South Tallinn, the counts of annual rows were 103 (age 110 years) at the height of 1.8 m and 134 at the height of 1.5 m, respectively. The latter tree stood in the yard of a residential house. Its annual rows were narrow, suggesting that the oak had grown for a considerable period of time in a dense stand (Sander *et al.*, 2008).

In the Lehmja oak stand outside Tallinn, M. Rohtla dated the oldest oak, popularly called "The Prophet", at 374 years in 2002. While the average age of the oak stand was 130 years, the ages of individual trees varied widely according to forest survey statistics (Parmas & Aru, 2012). The largest specimen of the oak stand was nicknamed "The Bridegroom" (H = 18 m, DBH = 142 cm, 1999) as a counterbalance to another oak of the past there called "The Bride" (Relve, 2003).

Outside the city of Kuressaare (approximately 3 km away) on the island of Saaremaa, West Estonia, there grows the Loode oak grove, which, as far as is known, has belonged to the city ever since the 16th century. The oaks there have been described in the 1980s as having low tortuous stems and large branches and being 150–300 years old (Kaar, 1964). Later, most of the trees (the thickest DBH = 113 cm, 2000) were dated at 200–400 years, with the age of the oldest oak (DBH = 80 cm, 2004 or 2005) being approximately 500 years according to the dendrochronological method (Läänelaid *et al*., 2008). At the same time, the age of the oldest oak (DBH = 94 cm, 2000) determined by the bark method was 450 years (Lember, 2000).

The outer bark method for dating old oaks in West Estonia in the 19th century was used in the settlement of Uuemõisa belonging to Uuemõisa (Neuenhof) Manor. The circumference of the thickest oak was 5.5 m at breast height (DBH = 175 cm, 1930?) and 6 m at ground level. Eight or nine oaks were growing nearby (DBH = 96–143, 1930?) (Vilberg, 1931). In 1999, five oaks were growing close to a residential house (DBH of three trees = 156–195 cm) and nine across the road on a wooded meadow (DBH = 89.5–164 cm, incl. a 4-branch tree). By the residential house, the outer bark thickness of the stoutest oak (DBH = 194 cm, 1999) was 11.6 cm (H = 3 m); at the sampling point (H = 2 m), however, it was 7.8 cm. The wear of the outer bark at that height was reckoned to be 3.8 cm. In the sample, 284 annual rows were counted and another 138 were added for the 3.8 cm wear, which yielded 422 years for the age of the tree. A neighbouring oak (DBH = 166 cm) had been struck by lightning 200 years previously, apparently resulting in its one half becoming dried and its stem hollowed out. The thickness of its bark was 11.2 cm at the height of three metres and 5.8 cm at the sampling point. In the bark, 211 annual rows were counted and 197 added for the missing 5.4 cm, yielding 408 years for the age of the tree. Further afield, a healthy oak (H ~ 26 m, DBH = 162 cm) afforded a 7.7 cm outer bark sample with 276 annual rows at the height of 1.5 m. It appeared that 12 mm of the outer bark crest (accounting for 43 annual rows) had worn off. The age of the tree was reckoned to be 319 years. The age gap between the two oaks of similar thickness but of different condition was approximately 100 years (Rohtla & Sander, 2000).

Lime dating by two methods and a critical assessment

Here, we draw on the findings of studies in Tallinn in 1999 (Läänelaid & Sander, 2004; Sander *et al*., 2008). In a raw 280-mm-long sample (55.6% of the radius) of a *Tilia cordata* Mill. (DBH = 109 cm) growing on the former diversely-built cemetery of Toomkirik (St. Mary's Cathedral) on Toompea Hill, 128 annual rings were counted. The dendrochronological method showed the tree to be 220 years old. The average annual ring width over the period of 1871–1999 was 2.2 mm; the tree had a slanting stem but was well preserved. The outer bark method has shown various ages for the lime – 280 years (Läänelaid & Sander, 2004) and between 300 to 350 years (Sander *et al*., 2008). It appeared that a 43-mm-thick outer bark obtained from the height of 0.3 m yielded 278 annual rows, and the presumably missing 16 mm was deemed to contain approximately 100 years' worth of annual rows. In the great fire of 1684 on Toompea Hill, the cathedral and several other major buildings perished, thus it is unlikely that the cemetery trees survived. During the rebuilding project in 1688–1691, there was intention to modify the cemetery walls (Maiste & Vohli, 1996). According to the 1728 plan, 34 trees were growing around the cathedral (The Great Plan, 1728); consequently, the greenery was restored or renewed. In 1774, burials by church buildings were banned. In 1778, the stone wall around the cemetery was probably demolished, and a major city square was constructed at Toompea (Maiste & Vohli, 1996). Dendrological research shows that the lime (DBH = 45 cm, 1871, without outer bark) may have stood there according to the 1825 Tallinn plan (Sander *et al*., 2008). The age of 378 years for the lime by the outer bark method, however, cannot be possible.

A *Tilia* × *europea* L. (DBH = 100 cm) growing near Niguliste (St. Nicholas') Church, apparently at the site of a former cemetery, yielded a sample of short increment (145 mm). The tree was in a bad shape, its top having been broken at some point of time. The sample constituted a mere 30.8% of the stem's heartwood radius (471 mm), and its year count was 146; hence the average annual increment from 1853 to 1999 was 1.0 mm. In the remainder of the radius, the annual ring widths were estimated to account for 110–212 years, establishing the approximate age of the tree at 280 years. A 36-mm-thick outer bark sample obtained at the height of 1.6 m showed 227 annual layers. Considering the counting error margin, the age was ascertained at 225–245 years (Sander *et al*., 2008). The age of a *T*. × *europea* growing in the yard of the pastorate of Niguliste Church was estimated at 300–400 years (Viirok, 1932; Anonymous, 1937). According to a legend, the church's pastor Christian Kelch, who died of plague in 1710, was buried under that particular tree (Viirok, 1932; Sander, 2009). Pursuant to another report, the lime was planted in 1680 (Sander, 1998). The 1728 data shows an abundance of trees near the church, as well, both at the then cemetery and in the form of two small alleys lining the footpaths leading to the church's front door (The Great Plan, 1728). An outer bark sample (59 mm) obtained from the lime (H = 13.5 m, DBH = 153 cm) at the height of 1.4 m in 1998 revealed 326 annual layers, hence the tree was dated to be 330 (between 320 and 350) years (Relve, 2003; Sander *et al*., 2008) old. Considering the age of the top layer of the outer bark, however, the finding is but little plausible.

The two southern rows of trees lining Kaarli Boulevard in Tallinn feature on the 1856 plan. By 1870, the boulevard consisted of four rows. In 1999, a sample of outer bark (31 mm) obtained at the height of 1.5 m from a *T. cordata* within the initial two rows revealed 168 annual rows. The age of the tree was estimated at 160–170 years (Sander *et al*., 2008). As the dendrological method was not applied, no assessment can be provided here.

The age of the stoutest stem (H = 17 m, DBH = 120 cm, 1998) of a six-branch sacred lime (*T. cordata*) in the village of Ilumäe, North Estonia, was 442 years based on an outer bark sample taken in 1999. From a heartwood sample, the age of the lime was derived to be at least three centuries (Relve, 2003).

Summary

In northern Latvia (previous Livonian province), oaks have been dated for at least 200 years, although initially on the basis of various trunk diameters. The study was carried out by forest researcher and owner of several manors Andreas von Löwis of Menar in the first decade of the 19th century. He was keen on learning the ages of oaks specifically. It appears that the species of *Quercus robur* has not been clearly defined historically and its variants *Q. robur* L. var. *tardiflora* Czern. and *Q. robur* L. var. *praecox* Czern have only added to the confusion.

Consequent significant events in Estonia included the beginning of dendrochronological studies with the increment borer in the 1920s and the following work in the 1960s. This research trend has continued until now.

Estonia also saw the adoption of a novel method by Mart Rohtla for determining tree age using tree bark. He identified tree bark as "all tissues outside the vascular cambium" (Angyalossy *et al*., 2016). This enabled tree dating by counting the annual rows marking tree outer bark increments. The results obtained were astounding, being both hard to accept and not easy to refute. It is unknown to what extent M. Rohtla was familiar with tree anatomy and the details of outer bark development, e.g. that the rhytidome is composed mostly of dead cells and produced by the formation of multiple layers of superized periderm, cortical and phloem tissue (Dickinson, 2000). However, the unreliability of bark layers in age assessment is accepted (Angyalossy *et al*., 2016). There may be considerable intraspecific variations in the (outer) bark properties. It may be thin or thick. Furthermore, in *Quercus robur* the outer bark may be ribbed, wide-fissured and platy (lamellar) (Mamaev, 1968). All this complicates outer bark annual row counting and dating.

The present overview introduces M. Rohtla's method to the international scientific community for forming an opinion and in the hope of it providing future inspiration for some. In addition, the ages obtained by this method were compared with dendrological data and, to a small degree, with historical records. The entire dataset was visualised, because statistical testing proved no reasonability due to lacking studies that would give information on the age of the outermost layers of the bark of studied oaks and limes. It appears that the ages are rarely matching. Moreover, the real meaning of the so-called annual rows in the outer bark of oaks and limes remains a mystery. The occasional coincidence nevertheless is representative of the actual situation, especially in younger oaks, which indirectly refers to the age of the topmost bark layers reaching 150 years. If we were to recognize tree dating by the outer bark method, among others, it might be included in the category of extended classical dendrochronology.

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