History and age of old limes (*Tilia* spp.) in Tallinn, Estonia

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Abstract

The historical park areas in Tallinn, Estonia contain many large lime trees (*Tilia* spp.) of unknown age. Since the available historical sources on these parks offer only fragmentary data, we decided to estimate the age of the limes using the tree-ring method and the bark method, along with the data from written documents and maps. Many of the limes grow on former bastions and their origin is related to the history of the fortifications of the city. Twelve lime trees were cored with an increment corer and their tree rings were counted and measured. The age of the trees was estimated by using cumulative graphs of annual increment. The ages of four trees were measured using the bark method of age estimation. This method relies on the counting of bands of phloem fibres in the outer bark. The age estimations of the trees by different methods were compared with historical data on the area. Despite some inaccuracies in the age estimations due to hollow tree trunks, the age estimations by tree rings and the bark method often coincided and was supported by historical sources. The accuracy of the graphical method of age estimation, and especially of the bark method, still needs to be verified in further studies.

Key words: bark, dendrochronology, phloem layers, Tilia spp., tree age.

1 Introduction

Trees in many ways are the antithesis of urbanisation. As surrogates for and fragments of nature, they are earnestly desired and yet paradoxically so gravely deficient in cities (Jim 1994). There are a number of functions that trees perform in cities (Mayer 1978).

The trees that have the greatest impact on their environment are the larger, more mature specimens. The old trees as living heritage could be equated with the historical monuments of the city, and be listed for special preservation by amending the existing Antiquities and Monuments ordinance. For privately owned selected large trees, consideration could be given to the allocation of public funds as subsidies for tree maintenance (Wicki 1988; Jim 1994; Nelson 1994).

The most valuable old trees in Tallinn are growing on the old bastions, where parks were established during the second half of 19th century. There are also old trees known to be growing near churches. These trees are important also in the European context. However, the age of the trees cannot be ascertained just by their appearance. Here an attempt will be made to assess the age of the trees by using historical sources as well as by measuring tree rings and the bark rings.

2 The study area

Tallinn, the capital of the Estonian Republic, is located in the northern part of the country on the coast of the Gulf of Finland, south of Helsinki (Finland) and to the west of St. Petersburg. Tallinn is the largest Estonian city, with an administrative area of 158.3 square kilometres and about 400,000 inhabitants (in 2001). There are several historical park areas in the city. Limes (*Tilia* spp.) are frequent tree species in these parks. The location of the investigated lime trees is shown on the city plan (Figure 1).

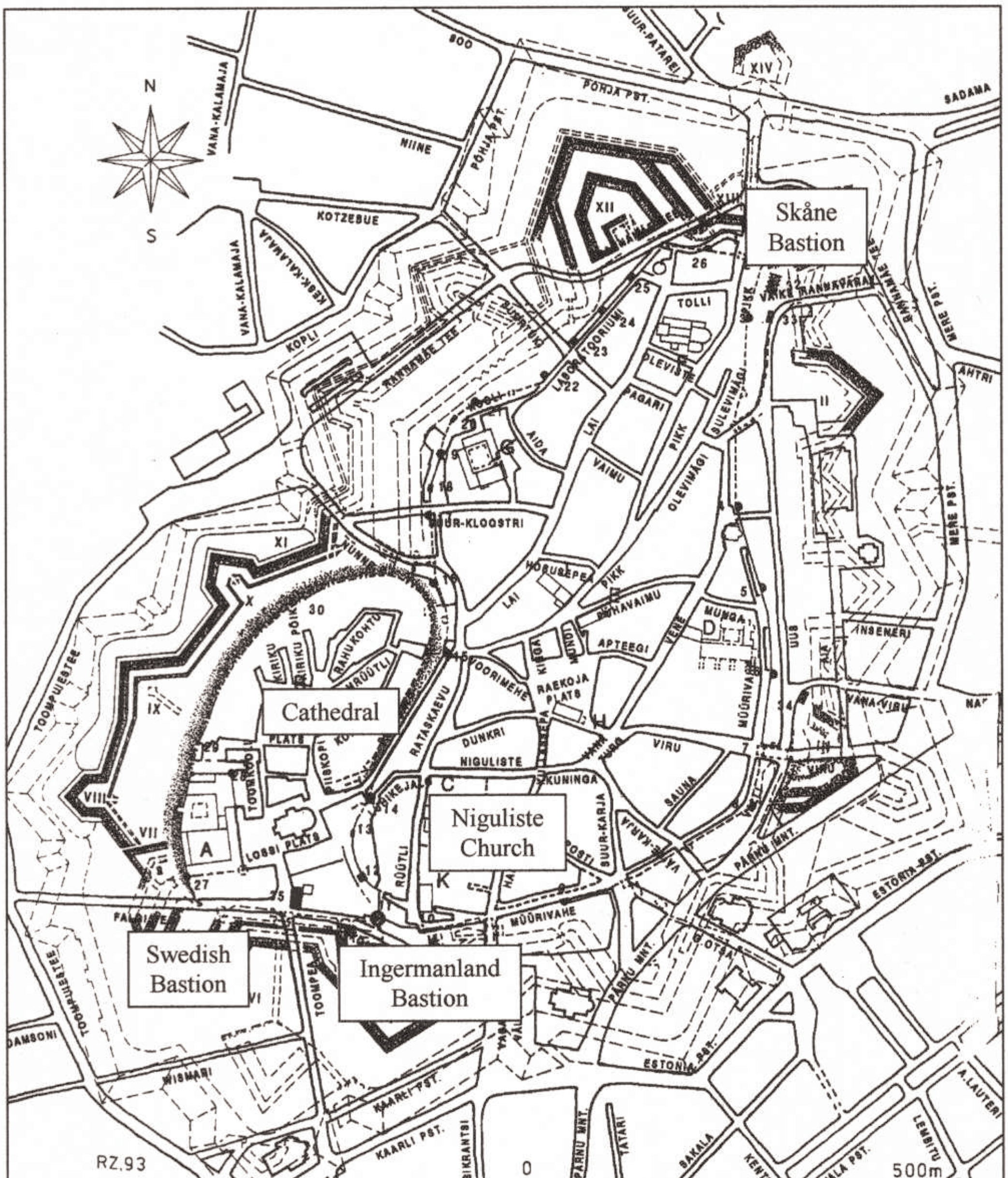

Figure 1. Former bastions and churches of Tallinn with sites of investigated lime trees.

The former bastions are generally favourable sites for tree growth, as the climatic and edaphic conditions are relatively stable there. The most serious threats to the trees on these sites are trampling, acts of vandalism, and air pollution. Nevertheless, citizens have, through the centuries, honoured trees of remarkable size. No doubt this positive attitude has played its role in the preservation of the big trees in the city to date.

3 Methods of determining the age of limes

Three methods were applied for determining the age of the lime trees: the tree-ring method, the bark method, and the historical method.

The tree-ring method

The initial principle of the method is very simple - counting of tree rings in the stem of the trees. The rings are available for counting in cores extracted from the tree trunk with a special age-corer. On the premise that every tree ring corresponds to a growth year, one could ascertain the age of the tree. Pigott (1989) estimated the age of limes from their stem thickness and tree rings.

Actually there are several hindrances in estimating the age of big limes (*Tilia* spp.) by counting their tree rings. Firstly, limes belong to diffuse-porous tree species. The boundaries of the tree rings of a diffuse-porous tree like lime are often hardly distinguishable even under the microscope. Secondly, an old and slow-growing lime tree can miss rings in some years (at least in some radii of the trunk) which means that the number of counted rings does not necessarily correspond to the actual age of the tree. Thirdly, as mentioned above, big lime trees are mostly hollow; they lack tree rings in the inner portion of their trunk altogether.

In these circumstances we had to elaborate a method for the assessment of the age of thick hollow trees like limes. This method is based not only on counting but also on measuring the widths of the tree rings of the lime tree. The measured ring widths are then cumulatively summarised and the cumulative sums of annual increment are represented as a line graph (Figure 2). The length of the missing part of the radius of the tree trunk (the portion of the radius in the hollow) is calculated from the girth of the trunk. The graph line of the cumulative increment can be extended back to the theoretical centre of the stem (the pith), taking into account the smooth increment tendency. The crossing of the graph line with the abscissa shows the probable onset year of the tree, i.e. the zero age at the height that the core was extracted from the tree trunk. The cores were usually taken from a height of 1.1 to 1.3 m above the base of the tree. As the limes were presumably planted, the established onset years at a height of 1.3 meters should not differ much from the planting year of seedlings of a similar height.

The bark method

It has long been known that the thickness of the bark of tree species with non-abscissive bark is related to tree age (Trendelenburg & Mayer-Wegelin 1955). Besides, the non-conducting outer part of the bark, or the rhytidome, contains layers in some tree species (Esau 1953, 1964). Fritts (1976: 68) notes: "The thickness of bark is a function of the tree's heredity, the vigour of the tree, and its age". In his voluminous handbook on dendroecology, Schweingruber (1996) also remarks on the growth zones in the phloem and bark of many tree species. It was established that in Central Europe 55 of 77 species exhibit distinct phloem-tree rings (Holdheide 1951, after Schweingruber 1996). However, the above-named authors still remain sceptical about using the counting of bark rings for estimating tree age.

The bark method of establishing the age of limes and oaks was developed by Mart Rohtla, Institute of Cybernetics of Tallinn Technical University (Rohtla 1998; Läänelaid et al. 2001). It is an original method of counting the fine layers of fibres of the phloem in the bark sample of a tree. This method has some disadvantages as well as advantages compared to the tree ring method. The difficulties are that firstly, lime trees can form several layers of phloem fibres during one vegetation period, especially when young. An additional fibber layer may also appear as a reaction to browsing of the tree crown in the park. Secondly, the outermost layers of the bark ribs of old limes are often weathered away and the approximate number of the lost growth layers can only be assessed by the fan-like shape of the converging pith rays in the cross-section of the bark rib.

The main advantage of the bark method over the tree ring method is that, regardless of the hollow tree trunk, its bark can be available for study almost in its entirety. This makes the bark method especially valuable for determining the age of hollow trees. Rohtla determined the age of some big lime trees in Tallinn using both the tree ring and the bark method in parallel.

History of old planted trees

In the 17th century, a Dutch type bastion front was founded, which was completed at the beginning of the 18th century. The Northern War between Russia and Sweden (1700-1710) ravaged the whole country, and Tallinn became the centre of a province (gubernia) of the Russian Empire. The Tsarist government of Peter I was not much interested in fortifying Tallinn. In 1710-1721 the Great Coast Gate and Skåne bastions were strengthened. Between 1750-1790, construction works were carried out (Vilbaste 1965; Zobel 1994, 2001).

It has been noted that trees made their first appearance on the fortification plans of Tallinn in 1728 (Kenkmaa & Vilbaste 1966). The plans show that 19 or 20 trees were planted on the Skåne bastion. Zobel (2001) agrees that the trees on Skåne bastion represented on the city map in 1728 were planted during the Swedish period.

The fortification plan from 1728 shows large amounts of trees inside the city wall near churches (the Cathedral, the churches of Niguliste and Oleviste) and along the streets of the old Town. Trees near the Cathedral have obviously been planted after 1684, when the buildings on Toompea Hill perished in fire and were subsequently mostly demolished.

The best overview of the trees growing in the city centre as of the early 19th century is given by the city plan of 1825, prepared by Üprus (1965). The plan shows many private and church gardens, trees on the bastions, and one City Park (founded in 1822). 145 trees were growing on eight bastions and 67 of them on the following three former bastions: Skåne bastion - 39, Swedish bastion - 17, and Ingermanland bastion - 22 trees. We do not know if the trees originating from 1728 were still growing on Skåne bastion at that time or not.

The trees on the bastions have probably been planted during the period 1750-1790, when the bastions were restored and renovated (Kenkmaa & Vilbaste 1965). Unfortunately, there is no data available about the planting of the trees. Trees are not depicted on the city plans of that period.

After the demilitarisation in 1857, some of the ramparts were preserved, some levelled, and some turned into green or residential areas.

According to the data of Viirok (1930), trees were still growing on only three former bastions in 1928 - the Skåne (since 1884 park of Rannamägi), Swedish (since 1862 park of Lindamägi), and Ingermanland (since 1862 park of Harjumägi) bastions, with a total of 55 old limes; 34, 10 and 11 trees growing on each, respectively. In 2001, 23 of these limes were still obviously growing, 10, 7 and 6 trees on the respective bastions. Of course, it is difficult to guess which trees on Skåne bastion originate from 1825.

4 Results

Let us explain how, using the cumulative graphic line and the growth rate of younger limes, we assessed the age of a lime tree. Here are some examples to illustrate the method.

Figure 2 serves as a good example of how the graphical method of age assessment works. Small-leafed lime (*Tilia cordata* L.) No. 10, next to the Cathedral, yielded a series of 146 tree rings. From the perimeter of the trunk, 342 cm, the radius of the trunk was calculated as 54.4 cm. To get the radius of the xylem or wood, the

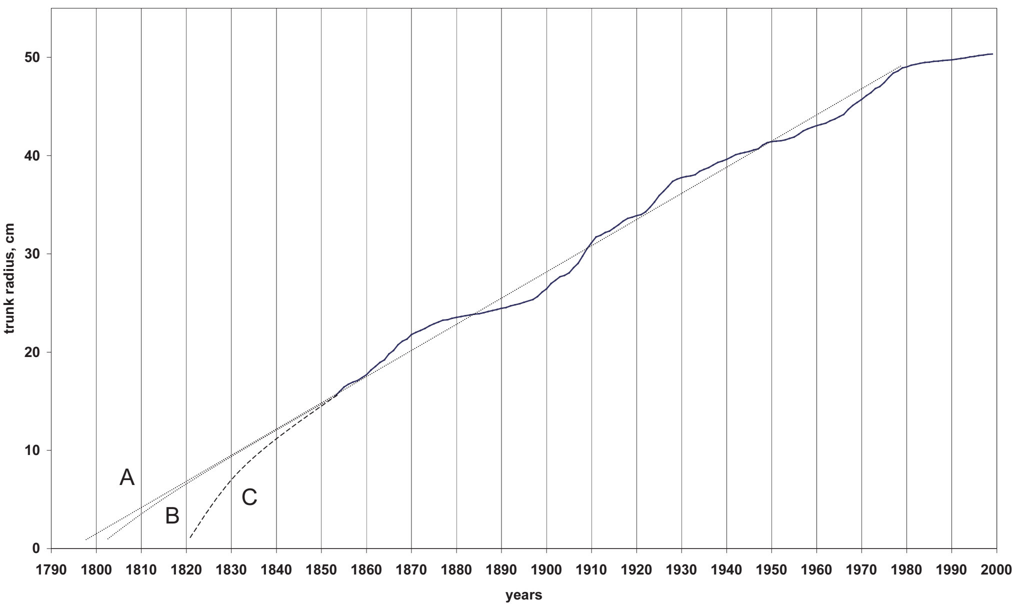

Figure 2. Cumulative annual increment of trunk radius of common lime (Tilia cordata L.) No. 10, growing next to the Tallinn Cathedral. Dashed lines - extrapolated growth models.

thickness of the bark was subtracted: 54.4 - 4.0 = 50.4 cm. The length of the raw sample core, or the cumulative sum of the measured tree-ring widths in it, 34.9 cm, gives us the existing portion of the radius. As the last ring, formed in 1999, located at the end of the radius of the tree trunk, we can easily find the radius of the missing inner part of the trunk: 50.4 - 34.9 = 15.5 cm. This is the distance we have to fill with tree-rings of hypothetical widths. First, assuming nearly constant annual increment of wood throughout the lifetime of the lime tree, a linear line was drawn as an extension of the cumulative curve to the x-axis (the fine dotted line A). We know that the annual increment of trees at a younger age is greater than at an older age, hence the number of wider tree-rings in the same radius of tree trunk is smaller at a greater distance from the centre of the trunk. Therefore, the linear graph obviously overestimates the age of the lime tree.

The question arises how big the annual increment of wood in limes at a younger age is. To answer to this question, we also sampled six younger lime trees in Tallinn. These European limes (*Tilia × europaea* L.) grow on the same bastions and near the churches together with the older trees. They have been planted there later, between the older trees; they have no hollow in the trunk and their increment cores extended very close to the pith. Two of these younger trees grow on the Ingermanland Bastion, one on the Skåne Bastion, one on the Swedish Bastion, one near St. John's church and one next to the Niguliste church. The cumulative growth curves of these limes look similar (Figure 3): during the first thirty to sixty years of their life radial increment is higher and then stabilizes smoothly at a lower level. Some exceptional growth can be seen in lime No. 17, growing on Ingermanland Bastion: the increment increases again in the last decades of the life of the tree. This feature is probably caused by changes in the light conditions of the tree.

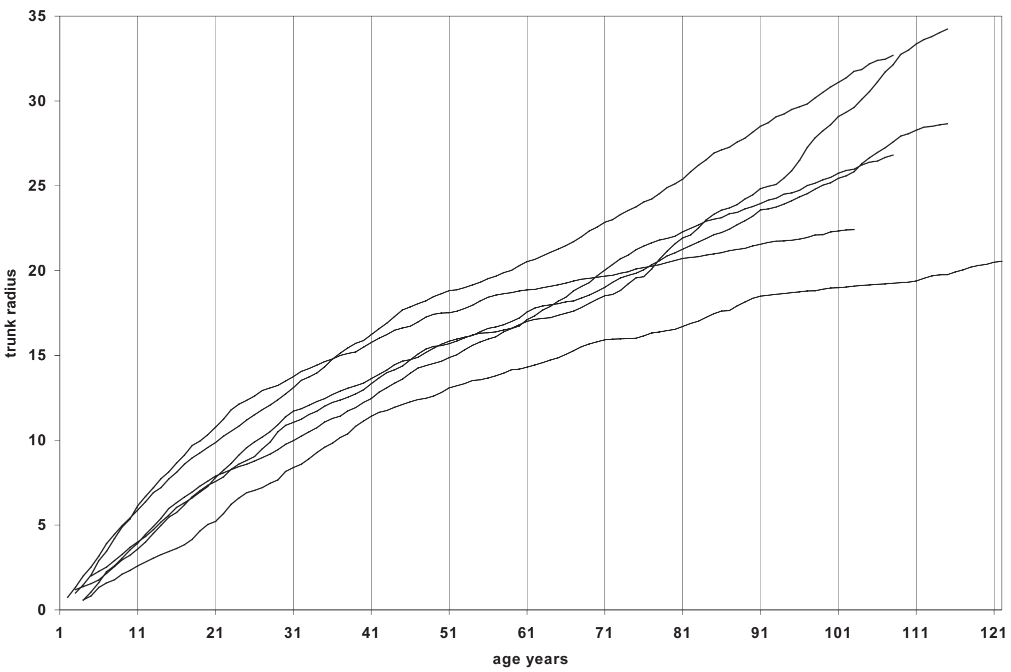

Figure 3. Cumulative increment of limes (No. 7, 9, 17, 18, 19, and 22) at a younger age. Abscissa - age of tree in years, ordinate - radius of the tree trunk.

The average annual increment of the younger trees during their first 100 to 121 years of life extends from 0.17 cm to 0.29 cm (for comparison: the average ring width of the old limes is 0.12 cm). During this period the wood radius of their trunks reached from 20.5 cm to 33.0 cm. In most of the older lime trees, the inner, missing part of the radius (hollow) has just about the same size. Hence we can use the increment rate of the younger limes as a model for the older limes, to fill the gap in their radius. If we assume the same growth conditions during the young age of the now older limes, we can apply the same average growth rate, from 0.17 to 0.29 cm per year, for the inner portion of their trunk. This is the first hypothesis. In Figure 2, curve B shows the hypothetical growth in the case of an average tree-ring width of 0.30 cm, while in the case of average tree-ring width of 0.17 cm the curve would start from the year 1762. This means that the growth of this lime was even slower at a younger age than at an older age. This seems unlikely. The trees on the bastions had initially been planted on an open area, without competition for light between the neighbouring trees. In such a case their ring widths could be even larger than 0.30 cm. This is the second hypothesis. But how wide can the tree-rings of young limes be? Neglecting extremes, rings of 1 cm width are possible, but not especially probable here: if the recorded outer tree-rings in the core are about 0.2 cm wide, it seems unrealistic that before they were on average five times as wide, and then suddenly decreased. In this case, smooth extension of the graph curve can help to restore the hypothetical growth of the tree at a younger age (hypothesis three: line C). In the case of lime No. 10, the third hypothesis, curve C, seems to be the most appropriate for restoring the growth curve of the tree. Lime No. 10 appears most probably in about AD 1820, making the tree about 180 years old at the time of sampling.

Here we have to take into account that the crossing point of the growth curve with the x-axis indicates the zero-year of the tree at the sampling height. For the actual age of the tree, one has to add the number of years the tree needed to grow to reach the sampling height (1.2 m in this case). That period could last approximately ten years. So the actual zero-year of this lime can be about 1810. Nevertheless, this result unfortunately does not coincide with the age determined by the bark method, i.e. zero-year AD 1719. The difference between the two age estimates is 91 years. We can state that, in this case, the age obtained by the bark method is possible (the period after the city fire of 1684), but not especially probable.

Wider tree-rings mean that the age of the trees is smaller for a given perimeter. Table 1 shows the ages of the limes as probable intervals of the zero-years. The first year of each interval shows the zero-year of the tree assuming minimal tree-ring widths (average 0.17 cm) during the younger age of the tree. The last year of the interval marks the probable zero-year in the case of maximal ring widths (average 0.30 cm) during the younger age of the tree. Assuming wider than 0.30 cm tree-rings in youth, the limes can be even younger than indicated in the table.

Figure 4 represents a more complicated case, namely the cumulative growth of the radius of the tree trunk (the solid thick line) of European lime (*Tilia × europaea* L.) No. 14, growing on Ingermanland Bastion (Harjumägi). As the tree was hollow inside, we could not obtain a core covering the whole radius. The growth of wood in the inner part of the radius has been extrapolated. First, if we assume the lime tree has grown with a stable average growth rate throughout its lifetime, we can extend the linear trend of growth, A, until a radius of zero. The crossing with the abscissa points to the onset year of the tree, in this case - AD

Table 1. Age of large limes (Tilia spp.) in Tallinn, determined by tree rings and the bark method.

Sample No., direction, sampling height	Location of the tree in Tallinn	Sampling date DD.MM.YY	Perimeter of the trunk, cm	Thickness of bark, mm	Length of raw wood core, mm	Number of tree rings in the core	Age in 1999 and onset years	
							By tree rings	By bark method
Tilia × europaea L.								
1 S 1,1 m	Skåne bastion	19.08.99	**251**	**28**	**162**	**194**	317-264, 1682-1735	-
2 W 1,1 m			**246**	**28**	**86**	**136**	229-299, 1700-1770	-
3 SW 1,0 m			**241**	**28**	**136**	**137**	210-266, 1733-1789	-
4 SW 1,4 m			**295**	**28**	**175**	**147**	236-304, 1695 1763	-
6 N 1,1 m			**350**	**28**	**226**	**ca 175**	276-353, 1646-1723	-
8 N 1,25 m			**404**	**28**	**146**	**121**	277-397, 1602-1722	-
13 W 0,7 m	Ingermanland bastion	29.10.99	**274**	**20**	**141**	**117**	209-279, 1720-1790	-
14 W 1,1 m			**360**	**15**	**171**	**158**	287-386, 1613-1712	426, 1573
15 SW 1,5 m			**347**	**15…10**	**189**	**135**	251-340, 1659-1748	-
20 S 1,2 m	Church of Niguliste		**313**	**27**	**145**	**147**	256-339, 1660-1743	225…245, 1754-1774
	Church of Niguliste		**-**	**-**	**-**	**-**	-	340, 1659
T. cordata L.								
10 1,2 m	Next to Tallinn Cathedral	29.10.99	**342**	**40**	**349**	**146**	198-237, 1762-1801	280, 1719

1500. As trees usually grow faster at a younger age, the graph line should be steeper than the average. The opposite possibility is that we assume that the trees have grown with maximum speed during their younger age. Let us assume that the average ring width was up to one centimetre. In this case the graph line would look like E. Such a fast growth during forty years does not seem probable. This line obviously does not fit in with the next part of the graph. It does not seem likely that there has been so abrupt a decrease in growth rate at around 1840. Assuming an average annual increment of 0.5 cm, the growth curve looks like D, with starting point at AD 1764. The next curve, C, assumes an annual increment of 0.3 cm (the biggest average increment in the younger limes) and fits much better with the later part of the growth curve. It crosses the abscissa at about AD 1712. Curve B assumes average ring width of 0.17 mm (the smallest average increment in the younger limes); the crossing point with the axis is at AD 1613. It may be suggested that the actual zero-year lies anywhere between the years 1613 and 1712. The bark method yielded an onset year of 1573 for this lime, which presumes a slightly slower increment of wood than in the case of curve B, but is possible. So, in this case the tree-ring age and the bark age nearly coincide. It means that European lime No. 14 already grew on Ingermanland Bastion before other trees were planted there in 1750-1790. If, as found by the bark method, the planting of the

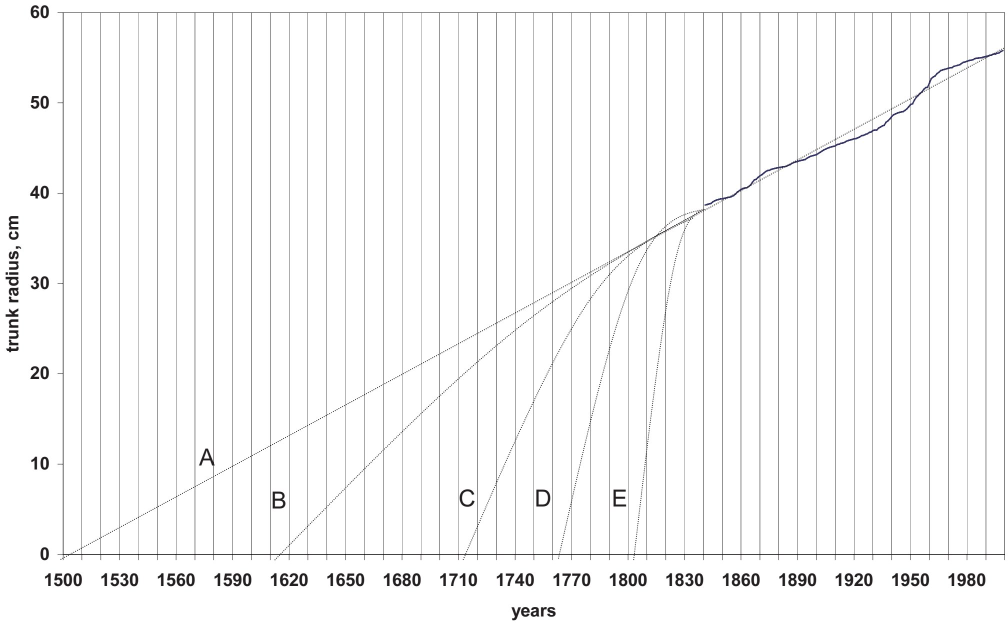

Figure 4. Cumulative increment of Tilia x europaea L. No. 14 on Ingermanland Bastion. Dashed lines A - E - extrapolated growth models (see explanation in text).

other trees was begun in 1750, this lime tree would have been about 177 years old at that time. The age of this lime at the time of sampling was thus about 426 years.

The ages of the remainder of the lime trees were estimated in the same way. The bark method sometimes yielded a greater age (for limes No. 14 and 10) and sometimes a smaller age (for lime No. 20) than the tree ring method.

5 Discussion

The stems of the limes growing on the bastions and near the churches are knotted and hollow. So it is very difficult to find out their age by counting tree rings. Usually the increment core contained only the outermost tree rings just under the bark, while the inner part of the tree trunk was hollow. However, the age of eleven trees was assessed by the tree ring method. The calculated age of seven trees lay in the interval 220-300 years and that of two trees probably exceeded 300 years (Table 1). Those two trees grow on the bastion of Skåne and Ingermanland. Unfortunately there is no historical evidence about these trees of high age. Maybe, the tree on Skåne bastion is represented on the city plan from 1728.

The old common-lime trees (*T.* × *europaea* L.) growing in the Niguliste churchyard (former cemetery) were also investigated. The age of one of them, calculated by the bark method, appeared to be 340 years. The age of another lime, calculated from tree rings, was 339-256 years (onset AD 1660-1743).

Probably the oldest introduced tree in the whole of Tallinn is the first common-lime that stands near Niguliste church (in the former yard of the pastor's house). Its height is 16 m and trunk perimeter 480 cm (2001). This tree is known as the

Lime of Kelch. Its indicated planting time is the year 1680 (Sander, 1993). Under this tree Christian Kelch (born 1657), the famous chronicler and pastor of Niguliste Church, has reportedly been buried on December 13, 1710.

Next to the Tallinn Cathedral, a small-leafed lime tree (*T. cordata* L.) was investigated both by the tree-ring and the bark method. The calculated age of this tree was 237-198 and 280 years, respectively.

The large hollows in the tree trunks can explain the different age estimations of limes growing even on the same bastion, and hence the big gap in the radius to be filled with tree-rings of hypothetical width. Therefore it is reasonable to present the age estimation as a period in which the tree could start its life.

Figure 5 shows the relationship between radius of the wood in the trunk and the maximal and minimal number of tree rings in it, based on the data from the six younger European lime trees from Tallinn. This graph can be used as a guide to estimate the number of rings absent in the hollow trunk of a lime tree, depending on the radius of the hollow. We see that for the smaller hollows, with radius up to 15 cm, the amplitude of fluctuation of the number of tree-rings is relatively small, while it increases in greater hollows, mainly due to the increase in the maximum number of tree-rings. The minimal number of tree rings occurs when they are the widest. The latter occurs when a lime tree grows up as a solitary tree, without having to compete with other trees for light and nutrients. In certain cases we can venture a guess as to whether the tree under investigation has grown up in the open or in a dense stand. For instance, the first small trees planted on the former bastions enjoyed plentiful light and grew well, whereas the trees planted additio-nally between the older ones suffered from shading and grew slowly during many decades. Depending on that assumption, we can decide if the actual number of

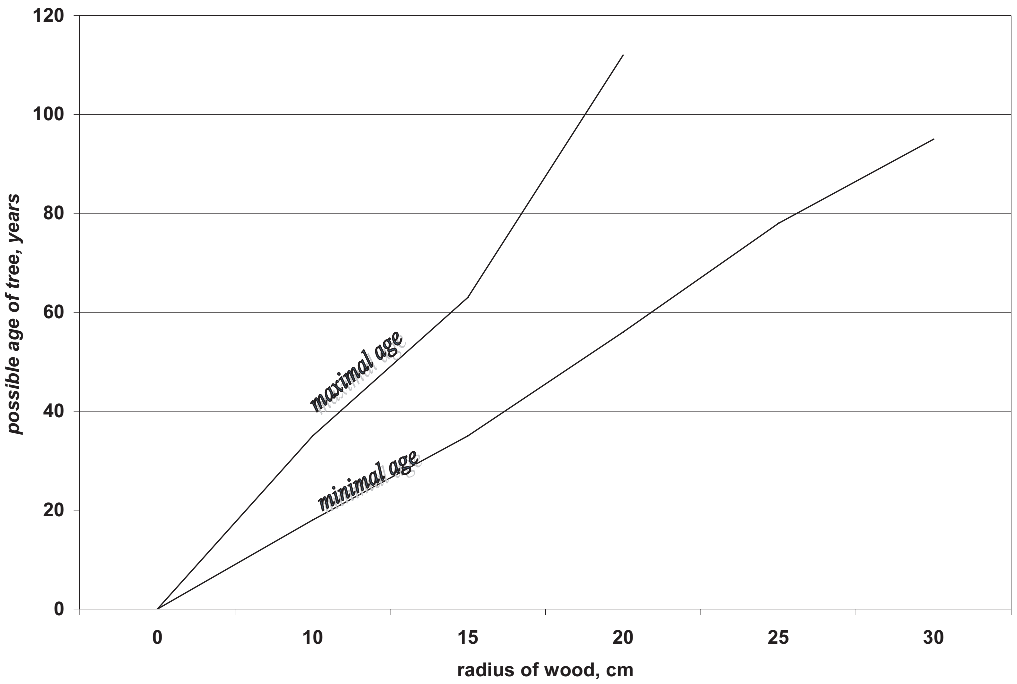

Figure 5. Minimal and maximal age of studied lime trees at different trunk radii. Abscissa - radius of wood in the trunk of lime, ordinate - corresponding possible age of the tree.

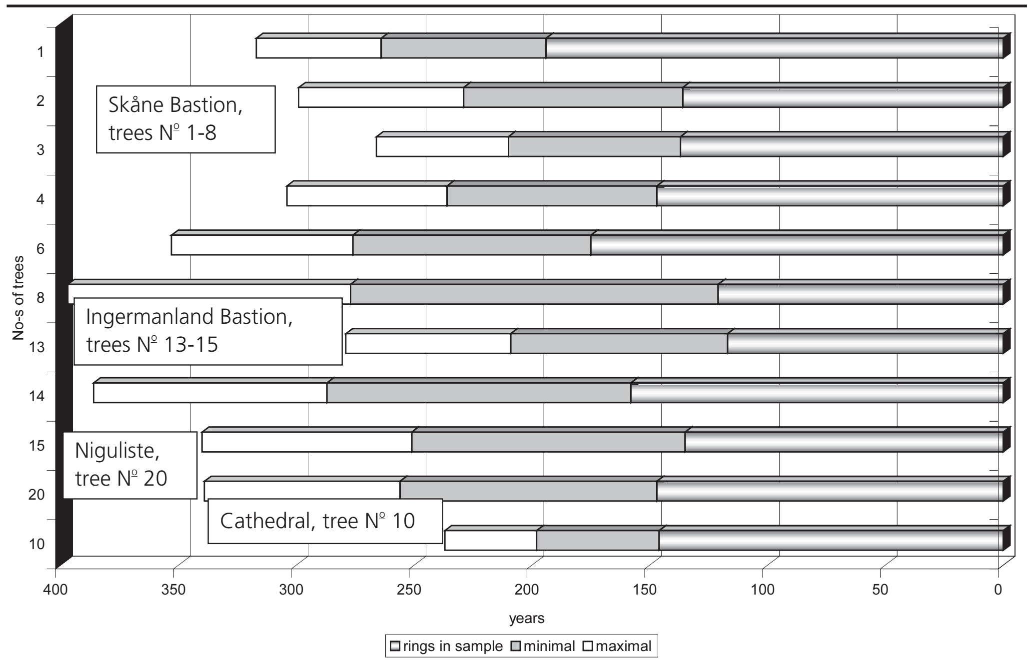

Figure 6. Temporal extension of ages of limes derived from cumulative graphs of ring widths. The extension of the white part of the bars at left is the possible onset period of the lime trees. For trees growing at Skåne Bastion the coinciding part of the white bars covers a period approximately 300-280 years before the present day. For three limes growing at Ingermanland Bastion the coinciding part of the white bars for two trees is about 340-290 years before the present day, while lime No 13 is younger, with onset about 280-210 years before the present day.

absent tree-rings in the hollow of the tree trunk tends more to minimal or maximal values.

Figure 6 shows a bar diagram of the extensions of the ages of lime trees, derived from the perimeter of the trunk and average ring widths in the sample cores and in the younger trees. The right part of the bars shows the counted number of tree-rings in the core. The middle part of the bars shows a minimal amount of tree-rings to be added to the counted rings, assuming the trees grew fast (0.30 cm/yr.) in their youth. The left part of the bars shows the maximal amount of tree-rings to be added, assuming the trees grew slowly (0.17 cm/yr.) in their youth.

We can see that of the six sampled trees from Skåne Bastion, three limes (No-s 1, 6 and 8) originate from a time more than 250 years ago (or before AD 1750), and three were planted between AD 1750-1790 (250-209 years ago).

Of the lime trees growing on Ingermanland Bastion, two were probably planted between 1750-1790, but lime No. 14 seems to be older.

Regarding the bark method, we have too little data at present to evaluate the appropriateness of the method. Apparently, the formation of several fibre bands during one vegetation period has in some cases increased the age estimate of the limes.

6 Conclusions

The age assessment of big lime trees (*Tilia* × *europaea* L. and T. cordata L.) growing on the former bastions and near the churches in Tallinn, using the graphical method of tree-rings and the bark method, has produced probable age intervals rather than the exact ages of the trees. The main reason for this is that old lime trees often have hollow trunks. Tree-ring samples can be extracted only for the outermost portion of the tree trunk, while the number of tree-rings in a big portion of the inner part of the radius remains to be guessed from the later growth rate. Together with old limes, six younger lime trees (*Tilia* × *europaea* L.) were sampled in the same sites, their increment cores extending nearly to pith of the trunk. These six lime trees served as a model of growth rate in young trees, which could be applied to the older limes. The relation between radius of the trunk of limes and the probable number of tree-rings in it is shown graphically. This relation helps to assess the number of tree-rings in the hollow trunks of old lime trees. Growth curves on graphs show the increment of the radius of the trunk visually, and help to correct the age assessments.

Although there are few references about growth layers in the bark of trees, our results from using the bark method generally agreed with the results obtained by the tree-ring method. At present we still have insufficient data on the reliability of the bark method of age assessment in limes, to recommend this method.

Age assessment of old specimens of European limes by using increment cores of wood is reliable as long as the core extends close to the pith. In the case of trees with a hollow in the trunk, the reliability of the age assessment decreases remarkably when the radius of the hollow exceeds 15 cm. The width of the assessed possible age interval of limes with a hollow of radius 20 cm can already be as great as 60 years. Historical sources can often give support to one or another age assessment of the trees growing in city parks and avenues.

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