Present State and Chronology of Oaks in an Oak Forest in Saaremaa Island, Estonia

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Abstract

The Loode oak forest in Saaremaa Island has long been used as meadow and pastureland, but there were no data about the age and course of radial growth of the big oaks. Age of 40 pedunculate oaks (*Quercus robur* L.) were assessed from the cumulative increment curves. The oldest sampled tree is about 500 years old. Correlation of the radial increment of oaks with climate data was investigated, also in temporal course. January temperature has a significant negative correlation and June precipitation has a significant positive correlation and in addition, since the 1960-ies April temperature has a significant negative correlation with the oaks' growth. The climate data of pointer years show that the combinations of affecting factors may be various. The investigation cannot confirm the thesis of forest decline in the Loode oak forest. The reasons for absence of young oaks probably come from the centuries-long management practice of the area.

Key words: pedunculate oak, radial increment, age assessment, pointer years, Loode, Saaremaa

Introduction

In the southern part of Saaremaa Island, near Kuressaare, there is a wooded meadow or oak forest called Loode Mets (Meikar 2008). The dominant tree species, comprising about 90%, is pedunculate oak (*Quercus robur* L.), but there are also ash (*Fraxinus excelsior* L., nearly 10%), aspen (*Populus tremula* L.), birch (*Betula pendula* Roth.) and pine (*Pinus sylvestris* L.) growing in the forest. The nucleus area of the forest, ca 32 ha, comprises a nature reserve since 1959 (Timm and Kiristaja 2006). The dominating soils are relatively humus-rich, but thin clayic and stony soils (Soil map of Estonia, 1:10 000).

In spite of conservation, health of the oak trees in the Loode forest seems to be poor (Figure 1). There are many dried branches in the crowns of oaks. The old oak trees are weakened by diseases. A few oaks have died. Most of the oaks are big trees; very little regeneration of oaks can be seen. Instead, in some places the understorey is dominated by ash. The conservationists and the publicity are concerned of the future of the Loode oak forest, as the area has served as a recreation place for citizens of neighbouring Kuressaare as well as for numerous guests of the town during a hundred of years already (Kesküla and Pao 2007).

We investigated the age and state of the oak trees in the Loode oak forest by using dendrochronology. The objectives of the study were to assess the age of the biggest trees of the forest and to explain the possible causes of decline of the oaks. Tree rings in the bored samples revealed the age and health of the growing trees.

Materials and methods

In the summer of 2004 and 2005 living oak trees were cored with 40 cm and 50 cm increment corer at height 100-130 cm and mostly from the north side of the trunk.

Figure 1. Scattered big oaks in the meadow-like forest. Right: twin oaks of Aavikute (No-s 7 and 8). The bigger of them (No. 8, left) is ca 394 years old (349 rings counted in the core)

Perimeter of each cored tree was measured by a metal measuring tape, as well as the thickness of bark at the sampling place. Altogether 40 oak trees were sampled. Cores were packed into numbered plastic tubes.

Ring widths of the oaks in 0.01 mm units were measured from the cores by using measuring device Lintab (Rinntech). The measurement and dating quality was checked by program Cofecha (Holmes 1983, Grissino-Mayer 2001). To establish the age of the trees, so-called method of cumulative increment was used (Läänelaid *et al.* 2001, Läänelaid and Sander 2004, Haneca *et al.* 2006). The measured ring widths of each tree were cumulatively summed and the temporal course of growth of the radius was reconstructed, using the trunk perimeter and thickness of bark. In the graphs of cumulative growth of the radius, a proper trendline was drawn on the graph in program Excel. The shape of the trendline was chosen to fit the general age curve of each individual tree. In most cases a polynomial trend was the best fitting with the cumulative increment curve. In the case of concave cumulative increment graph a linear trendline was chosen. The crossing point of the trendline with the horizontal time-axis shows the approximate zero-year or the year, when the height of the tree did not reach to the sampling height 1.3 metres yet. The zero-years of the oak trees were taken as the basis for age calculation of the trees.

According to the checking results with Cofecha, 24 best ring-width series were chosen for further dendroclimatological investigation. The Expressed Population Signal (EPS) (Wigley *et al.* 1984, Briffa and Jones 1990) was calculated to assess the common variance in these series. These 24 tree-ring series were standardized into tree-ring chronologies by program Arstan (Tree-Ring Lab, Lamont-Doherty Earth Observatory). The so-called residual chronology of 24 oaks was taken for dendroclimatological analysis alongside with monthly temperature and precipitation data from nearby Kuressaare meteorological station (about 6 km apart). The available tremperature record extends from 1948 to 2000 and the precipitation record extends from 1953 to 2000. Correlation of the tree-ring chronology with monthly air temperature and monthly sums of precipitation was calculated by program DendroClim2002 (Biondi and Waikul 2004). Further, the temporal course of the relation was investigated by calculating correlation for forward evolutionary intervals, for backward evolutionary intervals and for moving 36-year intervals (Biondi and Waikul 2004). The results of the analysis were depicted on graphs.

Event years in the tree-ring chronology of Loode oaks were found by using program Weizer (Gonzales 2001). The parameters for identifying the event years were chosen experimentally. For pointer years the event value threshold was set at 55% and window width 7 years with levels 50, 100 and 150. For pointer intervals the threshold percentage was set at 70.

Results

The assessment of age of the oaks by the method of cumulative increment and fitting growth trend showed that the age spectrum is wide. Their ages are reaching from the youngest, an over one-hundred-years-old tree, to the oldest, probably more than five hundred years old oak (Figure 2). The distribution of

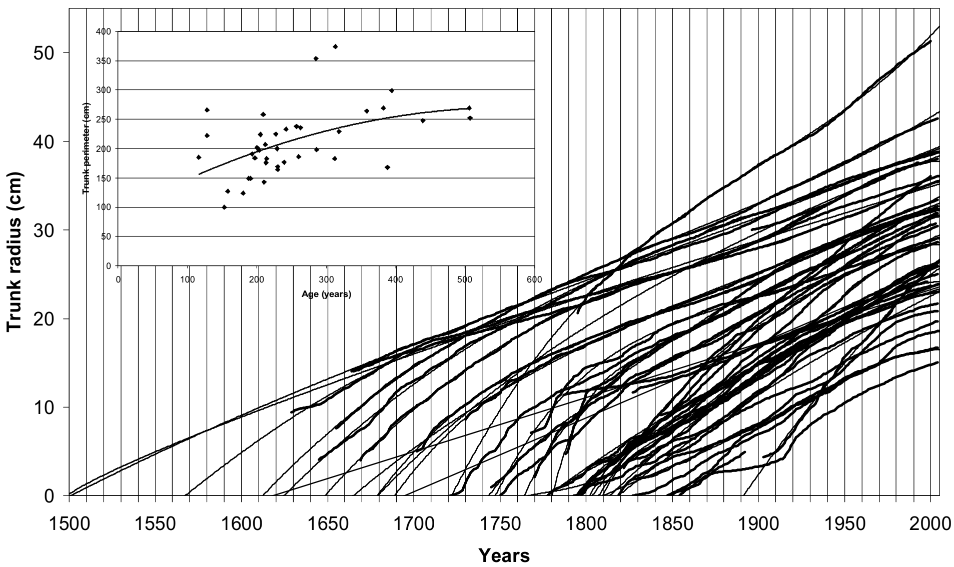


Figure 2. Cumulative radial increment of oaks. The crossing point of the trend lines with the horizontal axis shows the approximate onset of growth at the sampling height. Inset: relation of tree age (x-axis) and trunk perimeter (y-axis)

the onset years of oaks shows a conglomeration at about 1801-1810. A scatterplot of age and trunk perimeter relation was drawn (Figure 2, inset).

The Expressed Population Signal (EPS) of the 24 selected oak curves 0.97 exceeds the minimal level of 0.85 for a sufficiently replicated chronology. The dendroclimatological analysis has revealed that the Loode oak chronology is significantly related to January temperature (r = -0.28) and June precipitation (r = 0.37) (Figure 4). Correlation of the chronology in the forward evolutionary intervals appeared to be significant with January temperature and June precipitation in all intervals (Figure 5a). Correlation of the chronology in the backward evolutionary intervals appeared to be significant with the same variables in all intervals and in addition with April temperature in the six later intervals (Figure 5b). Correlation of the chronology with the climate variables in moving 36-year intervals was continuously significant with January temperature and June precipitation and in the later intervals also with April temperature (Figure 5c).

The combined pointer years for 26 oaks of the Loode forest were found: negative – 1990, 1983, 1973, 1959, 1956, 1950, 1940, 1931, 1918, 1909, 1893, 1888, 1868, 1863, 1845, 1831, 1809, 1804, 1786; positive – 1985, 1978, 1961, 1929, 1922, 1916, 1883, 1873, 1867, 1860. Only pointer years for period 1781-2004 covered by at least ten trees, are shown here. Climatograms of the recent combined pointer years are depicted in Figure 6.

Discussion

The radial increment of oak has been investigated in many papers (Briffa *et al.* 1983, Wazny 1987, Becker and Glaser 1991, Pukiene and Ožalas 2006, *etc.*). In Poland Golabek and Tukiendorf (2004) have studied growth phases of an oak tree during a hundred of years based on statistical analysis of cores from four directions of the stem. E. Szychowska-Krapiec (1996) has assessed the age of monumental trees in Poland.

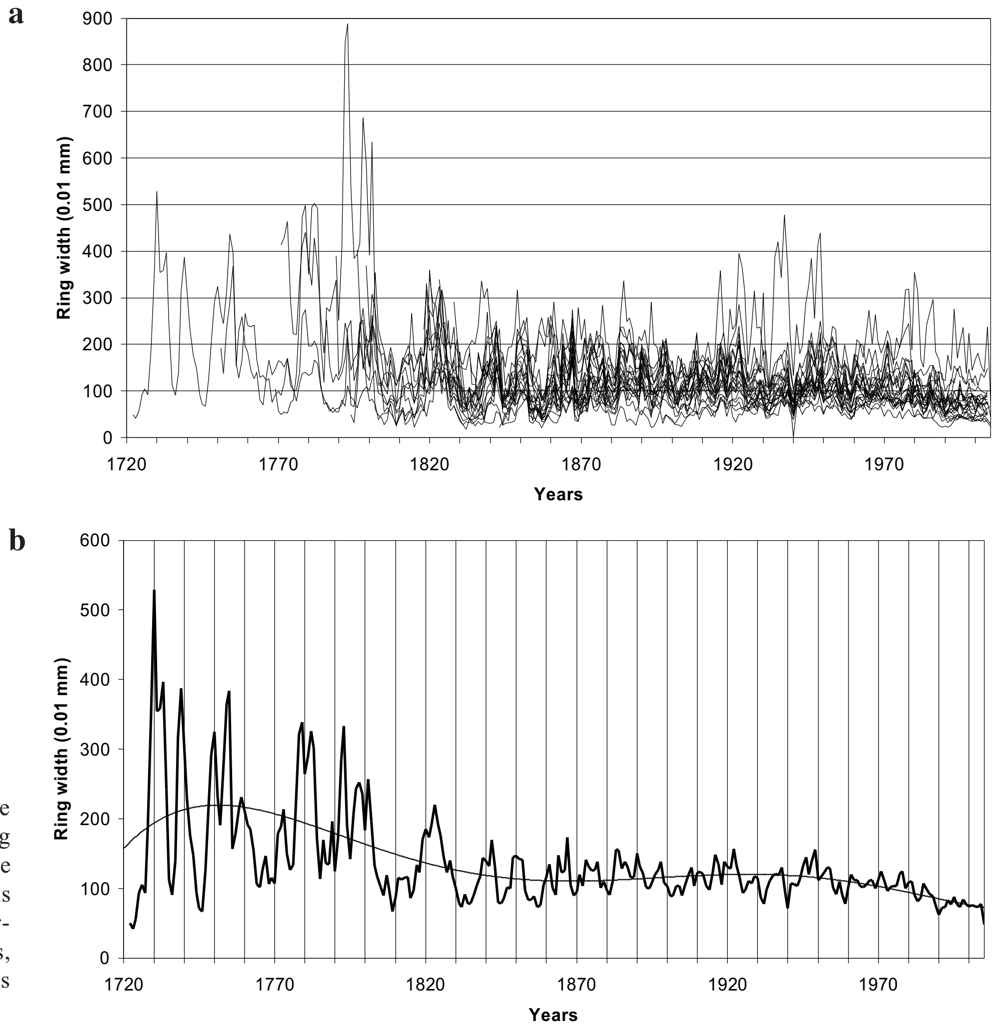


Figure 3. Temporal course of radial growth: a) tree-ring widths of 24 oaks, b) average tree-ring curve of these oaks with polynomial trend of order 5. Horizontal axis – years, vertical axis – tree-ring widths in 0.01 mm units

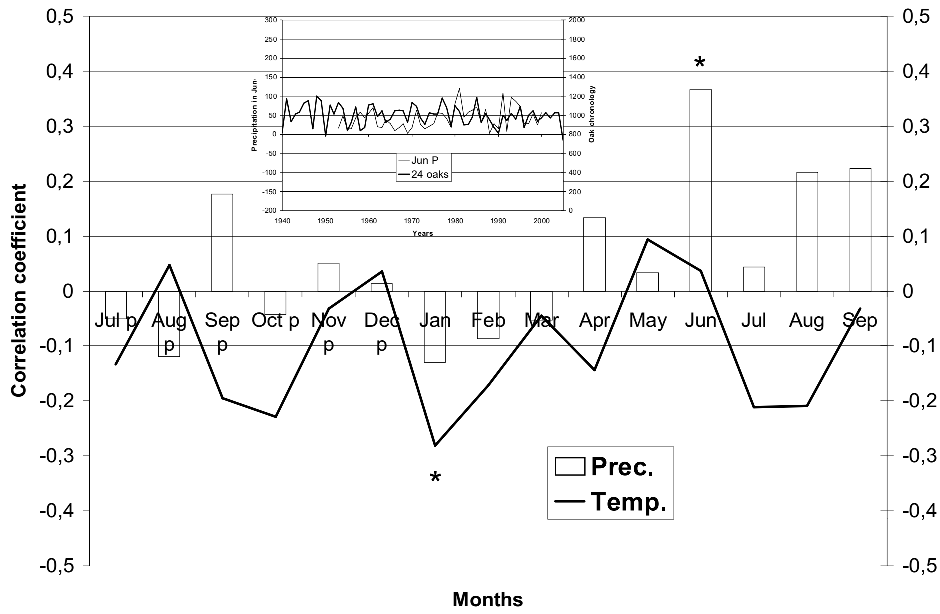


Figure 4. Correlation of chronology of tree-ring widths with monthly temperature and precipitation. Horizontal axis – months, vertical axis – coefficients of correlation. Significant coefficients at 0.95 level are marked with an asterisk *. Climate data from Kuressaare meteorological station. Inset: precipitation in June and values of the oak chronology (r = 0.366)

As the number of counted tree rings indicates the age of the tree, age determination is more complicated in the case of trees with hollow heart. E. Baniukiewicz (1974) has used a formula for calculating the age of hollow trees, based on the proportion of wider tree rings inside the trunk. That formula extrapolates the widths of the inner wider tree rings to the hollow (or uncovered by coring) part of the radius. Unfortunately, the determination of the zone of wider rings for the formula remains arbitrary and the result of the age assessment relates to that determination. Here we applied a graphical method of cumulative increment that takes into account the trend of widths of all available tree rings (Läänelaid *et al.* 2001, Läänelaid and Sander 2004). The question under discussion in this method is the choice of the type of trendline to apply to the measured cumulative increment. The simplest case is to apply the linear trend with the assumption that average ring width has been all the same throughout the age of a tree. We know that usually there are wider tree rings growing in the young age of a tree, just in that part of the trunk that will become hollow. It means that linear trend gives greater age than the actual age. If possible we fitted other trend types than linear. The most coinciding with the actual cumulative increment curve appeared to be polynomial curves of lower degree (up to 6). The premise of using polynomial curve is that the same tendency of radius increase has been valid since the beginning of the life of a tree. The preciseness of using polynomial curve is lowered in the case when the tree has long grown slowly in the first years of its life and the trendline does not reveal the S-shape of the beginning of the curve. Initial slow growth occurs in trees springing in the shadow of other trees. Fortunately, supposedly that is not the case in the Loode forest, as the site represents more wooded meadow than dense forest. The Loode forest has preserved meadow-like appearance already during several centuries (Meikar 2008). There are evidences on existence of similar pasture forests in southern Sweden since the 12th century (Bartholin 1978). This means that young oak trees have probably grown fast without notable competition since the very beginning of their life and approximation of their cumulative increment with a polynomial trendline is fully eligible.

The precision of age subtracted from the graphical cumulative increment method depends also on the diameter of the hollow of the trunk. If there is only a few centimetres of the radius to be covered by the trendline, the preciseness of age determination is rather good. If the radius of hollow is dozens of centimetres, the crossing point of the trendline with the time axis is not so fixed and can fluctuate in tens of years. We can assess the precision of the trendline from these cases when the measured ring width series extends to the pith of the trunk. We see that in the most cases the type of the cumulative increment is that of the trees grown in the open woodland, without growth suppression in the early youth.

The third source of imprecision of age assessment can be the eccentricity of the cross section of the trunk. Cross sections of oak trunks generally form concentric rings, but minor deviations occur in the case of tilted trees. In some oaks in the Loode forest there occur large knolls on the trunk. For instance, the perimeter of oak No. 4 (269 cm) was measured over two

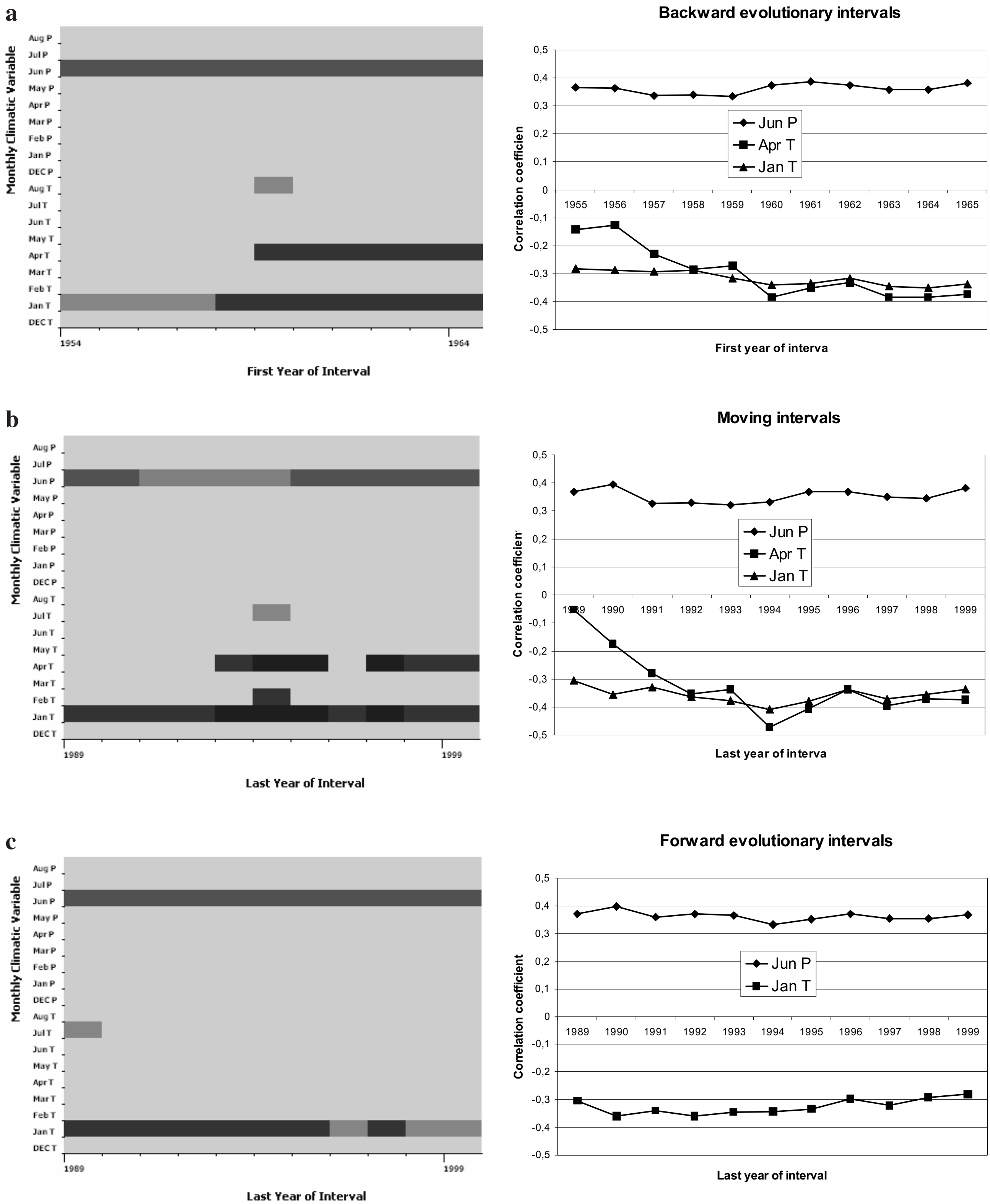
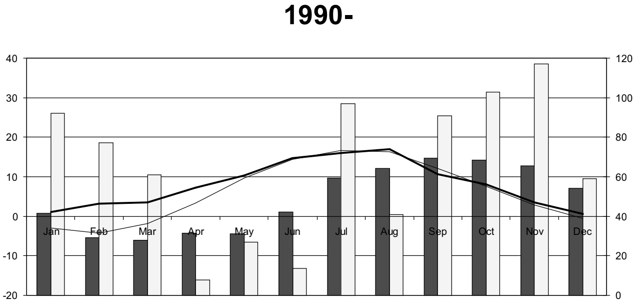
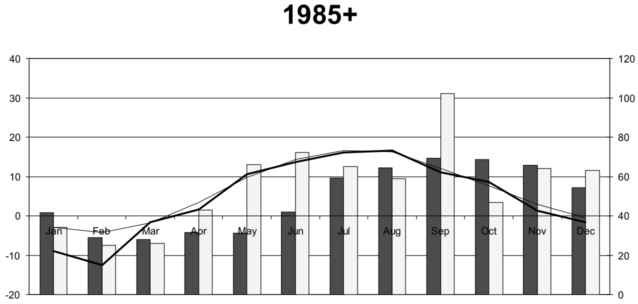
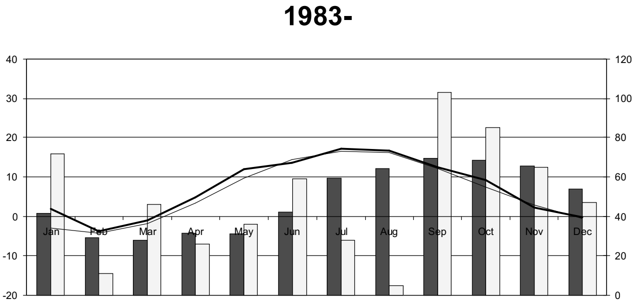
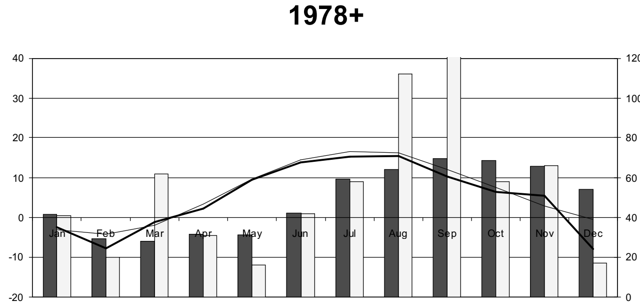


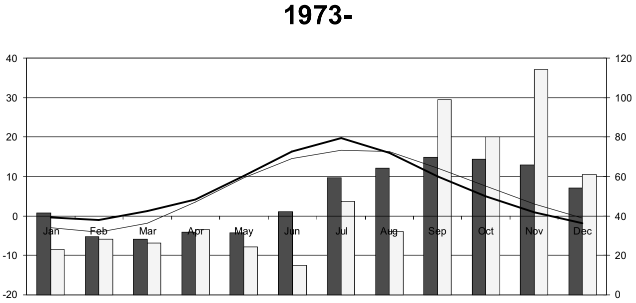
Figure 5. Temporal course of correlation of the chronology of tree-ring widths with monthly climatic variables in 1953-2005: a) in forward evolutionary intervals, b) in backward evolutionary intervals, c) in moving 36-year intervals. Upper graph: significantly correlated variables (dark stripes); horizontal axis – intervals, vertical axis – months of temperature and precipitation; lower graph: correlation coefficients (y-axis) in the intervals (x-axis)

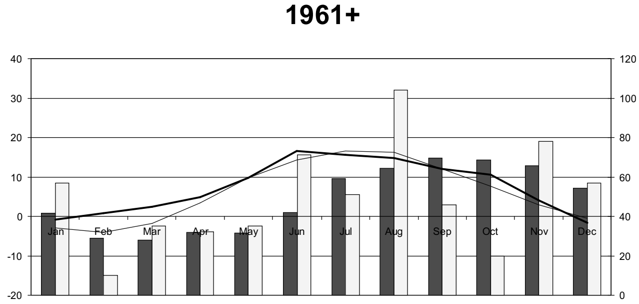


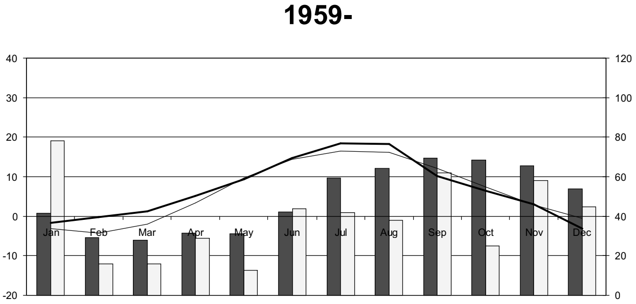












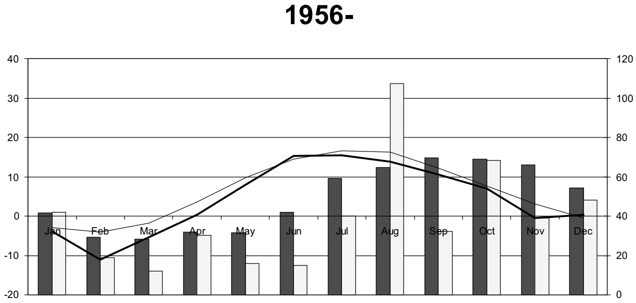


Figure 6. Clima-diagrams of recent combined pointer years (- = negative pointer year, + = positive pointer year). Horizontal axis – months of the year, vertical axis – monthly temperature (lines) and precipitation (columns). Thick line and light columns – data of pointer year, thin line and dark columns – average data of the climate record period 1953-2000 in Kuressaare

knolls at the sample height. This means that the actual concentric part of the tree trunk is thinner and the age assessment (500 years) derived from the trunk radius is overestimated. Thus there is only one sampled oak tree with probable age over 500 years – oak No. 13 with trunk perimeter 252 cm.

It was interesting to look for the possible footprints of past management of Loode area in tree rings. According to Meikar (2008), there were following changes in the Loode forest. Allegation that additional oaks were planted in the Loode forest for ship-building purposes in the turn of 16th/17th centuries was not proved by archival materials. Taking into consideration the screwy historical situation (period of wars) of that time, tree planting seems improbable. The sampled oaks do not allow to confirm or expostulate it. In the 18th century the Loode forest was mainly used as a forested meadow. In the turn of the 18th/19th century a conglomeration of young oaks emerged (Figure 2). That cohort of equal-aged oak trees would refer to a planting event in about 1800. There is no documentation about that planting, but it seems very presumptive in the frames of extensive forest planting in Saaremaa at that time. Since the end of the 18th century Loode area belonged to the town of Kuressaare. Most of the area was used as a hayfield and pastureland, while forest use was restricted to cleaning the hayfields from shrubs and sanitation cuttings (Meikar 2008). Also through the 20th century cutting has been limited with shrubs and young forest only, to preserve the old vital forest. Probably these are the main reasons why we cannot find young oaks in this forest today. In the first decades of the 20th century new forest cultures (apparently of oak among others) were established at the clearings of the oak forest and in the nearby pine forest. The average ring width series of the oak trees does not reflect the management changes. In 1959 a 32-hectar area of the Loode forest is announced a nature reserve. It means more care of the old oak forest.

Although it was stated that „it is not clear what climatological information can be derived from oak" (Schweingruber 1993: 199), our dendroclimatological analysis showed that the chronology of Loode oaks has significant negative correlation with January temperature and positive correlation to June precipitation (Figure 4). For comparison, the radial growth of pedunculate oak in the Bielinek Nature Reserve in Western Poland is significantly correlated with temperature of July-August of the previous year and May of the current year (all negative) and with precipitation of previous October, previous December, current February, April and June (all positive) (Cedro 2007). Siwecki and Ufnalski (1998) conclude that climate has a major influence on the vigour of oaks in Poland. We can draw a very general common feature with these oaks in Poland: the Loode oaks also react to temperature mostly negatively and to precipitation mostly positively. V. Rozas (2005) has found similarly that radial growth of mature and old-growth pedunculate oak (*Quercus robur* L.) in an old-growth woodland in the Cantabrian lowlands, northern Spain, showed a negative response to winter and summer temperatures, and a positive one to summer precipitation. It is known that water deficit limits tree-ring widths of oak (*Quercus robur* L.) also in central Europe (Bednarz and Ptak 1990; Smelko and Scheer 2000). In western USA white oak (*Quercus alba*) appeared to be so drought-sensitive, that it was possible to reconstruct precipitation history after its tree-ring chronologies (Blasing and Duvick 1984; Blasing *et al.* 1988). The results support the view that pedunculate oak is a drought-sensitive tree species also in the Loode forest in Saaremaa.

As there was an opportunity according to earlier dendroclimatological investigations on oak that the climate relations tend to change over time, we studied the climate relations in shorter periods. The analysis explains whether there is any temporal change in reaction of oaks to climate variables (Figure 5).

The forward evolutionary intervals showed two persistent variables having significant correlation with the tree-ring chronology: January temperature (negative) and June precipitation (positive). The former shows a slightly decreasing influence in longer periods. The backward evolutionary intervals analysis revealed a third variable, April temperature that has significant negative correlation with the tree-ring chronology only in the later periods after 1960. The moving 36-year intervals analysis shows also persistent correlation of the chronology with January temperature and June precipitation and additionally with April temperature during the later intervals beginning in 1958. It means that along with the two persistent variables April temperature has become a significant negative factor for oaks since the beginning of 1960. The climate record shows that in 1960-2000 April temperature has increased to 121% from the average of the previous period, 1949-1959. At the same time, January temperature has increased only to 105% and the annual average temperature to 106%. Significant decrease in duration of the cold period is observed on the sea coast of Estonia in the last fifty years (Jaagus 2003). Apparently warming in spring has exceeded a certain threshold in 1960, becoming a significant negative factor for Loode oaks. At the same time, January temperature has been a significant negative factor in all intervals, showing higher correlation with chronology in shorter forward and backward intervals and the highest correlation in moving 36-year interval 1959-1994. The most stable factor has been June precipitation, it has stayed persistently positive in all intervals.

The analysis of pointer years was carried out using experimentally derived most appropriate values of parameters for the calculations. To reveal only the most distinguishing pointer years, the combined data of pointer year and pointer interval analyses were used. The latest combined pointer year 2005 was omitted because of the assumedly incomplete tree ring of the sampling year. The negative pointer years are prevailing. Paying attention to the significantly correlated climate variables we see that in the negative pointer years January temperature has been mostly above average, except for 1956 with normal January temperature. In the negative pointer years 1956, 1959, 1973 and 1990 there is a common feature of scarce precipitation in the first half of summer, whereas the positive pointer years distinguish with normal or above normal amounts of precipitation (Figure 6). From the climatograms of the recent pointer years we can see that the probable reasons for formation of extremely narrow and extremely wide tree rings may be different, depending on the combination of temperature and precipitation.

There are investigations where the health of trees has been assessed mainly by the state of their foliage and crown (Golabek and Tukiendorf 2002; Stravinskiene and Šimatonyte 2006). In this case we try to find signs of growth deterioration from the series of tree-ring width. The average tree-ring curve of the 24 oaks shows steep reduction of the increment especially in the last fifteen years, 1990-2004, when the mean annual increment has dropped to 0.76 mm or 76.4% of the previous period of the same length (Figure 7). The general decrease in the average increment has begun already earlier, since the beginning of the 1950. The smallest average increment 0.62 mm occurs in 1990. Although, the ring width of 1990 is nothing extraordinary, as there were even narrower tree rings in certain years in many oak trees. For instance, most of the oaks formed a very narrow tree ring also in 1959, 1956, 1940, 1932, 1918, 1901 *etc.* We see that increment fluctuations have regularly occurred throughout the lifetime of the oaks and after growth suppression trees have relieved again. The oak chronology of the Mihkli oak forest, located on the continent some 85 km northeastward from Loode, shows similar decrease since about the 1950-ies (Läänelaid, unpublished). Thus the low increment of oaks in the last decades does not necessarily mean the specific decline of trees in the Loode oak forest. The profound investigation of oak decline in southern Sweden (Drobyshev *et al.* 2006) concludes that the most probable cause of oak decline is a drought event that may have effect with some temporal delay. Fritts and Swetnam (1989) have noted that there may be a number of less desirable dendroecological characteristics in the forests in Europe, as compared with the North American arid West, *e.g.*: 1) weak climatic signal and strong noise, 2) densely stocked stands with much possible interactions between stand dynamics, aging of trees and pollution, 3) the growth response to the various controlling factors may involve lags lasting for several years, resulting in autoregression and possible nonlinear or synergistic influences. Basing on these tree-ring data of one or two forests it is not reliable to state the forest decline in the region. As pedunculate oak can reach a thousand year age, these oak trees in the Loode forest are relatively young. For their present age and radial increment they could survive several hundreds of years more. It is still clear that the climate is going warmer in the region and spring temperature is rising. Accordingly, the reaction of oak trees to the rising temperature is changing. As a drought-sensitive tree species, oak reacts positively to mid-summer precipitation. If the average sum of precipitation in June is stable and the temperature in June as well, the trees can probably survive. Absence of young oaks in the area of the Loode forest means decline of the oak forest in the prospect of centuries.

Conclusions

The tree-ring analysis of oaks growing in meadow-like forest of Loode in Saaremaa Island showed that the age of the big trees extends to the beginning of 16th century. Thus the oldest tree of the forest is now about 500 years old. Most of the sampled trees are notably younger, 400-200 years old. It has to be mentioned that there are nearly no young oaks in the Loode forest, because during about two hundred years the area was used mainly as hayfield and pastureland and the understorey was cut.

Dendroclimatological analysis has shown that oaks in Loode forest are influenced by January temperature (negatively) and June precipitation (positively) during the whole period of climate record, 1953-1999. In the last 45 years (from ca 1960 forward) temperature of April has emerged as a new significant (negative) factor for oak growth. Apparently it is related to the rising average temperature in April.

Although there are lot of dry branches in the crowns of the oaks and the average radial increment during the last 15 years has been low (0.76 mm), the decrease of growth in this short period does not allow asseverate the decline of the Loode oak forest. It can be assumed that the present growth suppression will follow by a release as it has occurred during centuries before. In the premises of stable amount of precipitation in June and without burning or cutting the trees by man the oak forest might stand for centuries.

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СОСТОЯНИЕ И ХРОНОЛОГИЯ ДУБОВ В ДУБНЯКЕ НА ОСТРОВЕ СААРЕМАА В ЭСТОНИИ

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Резюме

Дубовый лес „Лооде” на острове Сааремаа долго использовался под лугом и пастбищем, но возраст больших дубов был неизвестен. Возраст 40 деревьев дуба черешчатого (*Quercus robur* L.) оценивался по графикам кумулятивного прироста. Старейшее дерево оказалось близко к 500-летнему возрасту. Изучалась корреляция радиального прироста дубов с климатом и изменение корреляции во времени. Температура января имеет существенное отрицательное влияние на прирост дубов, и атмосферные осадки июня имеют существенное положительное влияние на прирост дубов. Кроме того, начиная с 1960 г. температура апреля стала существенно отрицательно действовать на прирост дубов. Это очевидно связано с отеплением весенних месяцев в Эстонии, в течении последнего полувека. Климатические данные реперных годов показывают, что комбинации факторов в экстремальные годы прироста бывают разные. Исследованием радиального прироста дубов не подтверждается и не отвергается тезис ослабления леса в дубняке „Лооде”. Причины отсутствия молодых дубов в лесу находятся в двухвековой практике использования ресурсов лесолуга „Лооде”.

Ключевые слова: дуб черешчатый, радиальный прирост, определение возраста, реперные годы, „Лооде”, Сааремаа