Doctoral thesis

Relations between tree ring width and certain site parameters

Written by:

Csókáné Szabados Ildikó

West-Hungarian University

Faculty of Forestry, Sopron

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Tree-growth has been in the focus of the attention of forest researchers and practitioners since the early days. The most striking question was the speed of growth of tree-species and their individuals under given circumstances, because this could help in introducing proper management practices. The unfavorable environmental changes of the last decades (ascribed mainly to harmful side-effects of human activities) required new definition of the long-studied questions. It became important to know, which factors and to what extent influence the functioning of the environmental systems, what effects they have on tree-species and individuals.

The analysis described in this paper is focused on those changes induced by environmental factors, which are of high importance for the Hungarian forestry. One of these is the oak decline, which affected one of our most important native tree-species in large extent, and although being considered biotic damage, its development was largely influenced also by other factors. The decline threatened with degradation of one of our most valuable ecosystems, and affected forestry as an economical activity. A considerable amount of wood was lost due to the dying of trees, and the loss of increment was remarkable as well.

Tree-ring analysis is able to identify the occurrence, duration and development of the decline and its effect on tree growth, as well as to determine that increment loss, which did not result in tree mortality and neither forest inventories nor other data sources provide information on it. However, the current analysis is focused on the alteration of the tree-growth only, and leaves intact issues such as the enabling environment and the ecological damages following the decline.

The other key issue of the current study is the determination of the effect of precipitation on the diameter growth, i.e. the ring-width, where correlation can be found between growth and monthly precipitation and the role of this latter one can be quantified. This importance of this issue is underlined by the increased importance of the most recent climate change research, and in relation to this, the changes of growth observed on the level individuals.

Sampling and measurements

The tree-ring analyses were carried out by using increment cores from outstanding and dominant trees of long-term growth and yield sample plots of the Forest Research Institute, located in the Visegrádi and Börzsöny mountains. In order to enable easier comparation, the sample plots needed to be characterized by similar site conditions and thus be in “hornbeam-oak” climatic region, free-draining by hydrology and lessivated brown forest soil by soil type. The selection was also influenced by the fact that for comparative reasons a sufficient number of stands with the same and different ages were needed with the same or similar site conditions and in the same location. As a result of all these factors the sample was compiled from 116 trees with two increment cores each on 11 sample plots, covering a 30-70 years growth period. Based on the health condition observed in the year of sampling the sample trees were classified as follows: healthy (5); slightly damaged (4 or 34); dying or dead (32 or 2).

Megjegyzés: Agyagbemosodasos barba erdotalaj, hahahah

The ring width measurements were carried out by a Johann Digitalpositiometer using 1/100 mm resolution.

Data processing

1. Synchronization: In the course of measuring the ring-width, data are immediately entered to the computer and verified. The tree-ring series should be in a synchronic position, i.e. the location of maximum and minimum values should be identical in sufficiently high percentage (as defined by the length of the series).

2. Indexing: Each and every tree-ring series can be described by a function, which is able to define the growth trend for the whole life of a tree or at least for the measurement period. The most frequently used functions are the exponential ones (y = a e t), or the Huggershoff-function (y= a tb ect , where t stands for age, a, b, c are constants) which is able to describe the behavior of growth data much better. According to the available literature, this is the first application of this latter function in Hungary. This function is the combination of the polynomial and the exponential functions, and gives a very good description of the increasing growth pattern of the

young and the declining pattern of the old ages. During indexing the percentages of the measured values are projected to the selected function as the X axis, thus the index value defines the proportion of the real growth in percent of the expected value as defined by the function. In all calculations these age-independent index values are used instead of the original tree ring data.

3. Sensitivity analysis: this analysis is to compare the sensitivity of the different sample plots and to identify plots, which are to be left out from further analyses. Beside the analysis of the whole series it is important to know which periods are more sensitive and which are not worth analyzing separately due to the low possibility of new results. Sensitivity can be well used in selecting time intervals if we want to get information on the relations within the whole time series. By dividing the whole period into 10-year intervals it is possible to identify those ones where external factors induce the most remarkable reactions.

4. Autocorrelation: tree rings are influenced not only by external factors, but also by internal physiologic processes, which are largely affected by the internal environment. The ring widths are not only a series of random values, rather this is a statistically dependent series where, according to certain and yet largely unknown mechanisms, each ring affects the development of the next rings. The dimension of this effect and the number of rings under influence can be determined by the autocorrelation. The connection between one tree ring series with 1, 2, 3 etc earlier data series is analyzed as long as significant correlation is found. Normally the correlation decreases by each step back in time.

RESULTS

1. ANALYSIS OF GROWTH AND LOSS OF INCREMENT AFTER DAMAGE

1.1. Developing a method for calculating increment loss: When determining the loss of increment it is important to define the normal level of increment values. Yield tables are providing mean values determined for the whole country, thus hardly can be used to determine local losses accurately. A more solid basis can be established by using growth data of the healthy trees of a stand producing “normal” development. They can represent the increment values of a certain stand unaffected by damages. Theoretically the increment curve of the undamaged reference trees and that of the damaged trees would follow the same pattern as they did before the beginning of the damage. This theory is applicable also in those cases where the reaction to certain influences is weak and short in time. It is particularly true when a minor damage results in a loss of a certain portion of the increment: for example, when the increment of a certain year is expected to be high due to the favorable weather conditions, but this increment is slightly decreased by an insect attack, this loss is detectable even in this relatively high increment.

This method considers that there were or could be differences between the growth patterns of the reference trees and trees subject to subsequent damages. In order to define this difference the growth pattern of the reference period preceding the damage period needs to be determined.

The regression curve describing the tree ring series of the time interval very likely free of the effect of the damage (i.e. from the earliest date till the expected occurrence of the damage) should be calculated then this curve should be extrapolated to the interval of the damage. It is important to note that extrapolation for both groups of trees (reference and damaged) should be based on the data from this unaffected period, otherwise the comparability is seriously distorted. When the function is defined, then an indexing is needed to show modification of the growth of the reference trees due to the external factors. These index values are hypothetically the same for the damaged trees, i.e. the external factors would alter their growth the same way as they did in case of the reference trees. Obviously the real index values for the damaged trees are different, so the loss of increment due to the damage can now be calculated as the difference between the annual index values.

1.2. The growth patterns of the individual healthy trees are very different, due to the effects of the weather and the silvicultural treatments. Such values are very different from those of the yield classes of the yield tables. Since the measured values are characteristic for the individuals, they do not allow conclusions for the whole stand. It is obvious however, that the sample trees could have produced higher growth than the whole stand, since they belonged to the outstanding or dominant height classes. Due to the sampling method, the trees could migrate to the next or second next yield class till the end of the observation period, but in fact trees drifted to the lower classes in five cases (Szendehely, Pomáz, Szentendre 75H, 77E, Pilismarót), improvement was observed in Pilisszentkereszt only.

1.3. The long-term data series of the radial growth describes a decreasing trend, fitting well to the thesis of growth declining by age. Two exceptions were found however: the radial growth of the sample trees showed and increasing tendency between the age of 22 and 91 years, and especially in the last 30 years. An alternating growth tendency characterized the 46 years old sample trees of the Szendehely 14A stand. The whole observation period showed an increase, mostly due to two peaks, one between 1964-73 and another one between 1979-83, but a strong decline of growth was observed in the last ten years.

1.4. In the course of the re-assessment of the health conditions it was concluded that there were no changes in the 64% of the undamaged sample trees, 31% moved from class 5 to class 4, and only 5% died or was removed from the stands.

The damaged trees showed more substantial changes during the 8-year period concerned: 58% remained in the same damage class, 25% deteriorated, 7% died or was removed, and the condition improved in case of 10% (3 trees). The improvement meant a move from class 4 to class 5 in each case. Sample trees in more severe damage classes have never recovered completely.

In conclusion, the health condition of one third of all sample trees deteriorated between 1994 and 2001, and only very limited improvement was observed. On the basis of these observations it should be underlined that the oak decline is still of importance and has its actuality.

1.5. The occurrence of the oak decline can be determined from the deviation of the growth patterns of the sample trees with different health condition. For obvious reasons, these years of deviation do not identify one single point in time. According to the literature the decline showed a certain spatial and temporal development, and the individual trees showed the symptoms of damage in different dates. Forest protection experts identified 1981 as the starting year of the decline, but tree ring data showed earlier appearance of the damage. The patterns of tree ring series differentiated as early as the beginning of the 1960-ies in several sample plots, so links were found between the development of oak decline and the growth of trees in the period preceding the decline. A logical conclusion could be that those tree rings show a predisposed condition of the sample trees more perceptive to the decline.

Since the sample plots are located relatively close to each other, the above evaluation is valid for this area only and has yet to be proved for other locations, but the method itself is universally applicable.

1.6. The dimension of the increment loss: an extended damage period, regardless of the reasons, results in a loss of increment of a various degree and could cause such losses even before the visibility of the damage. Using the growth pattern of the undamaged or healthy trees as a reference the loss of increment can be calculated in a way that site and climatic conditions are also taken into consideration. The sample trees showed 26-30% of increment loss in the average of 14 years, but this average is a result from a very wide range: in 1991 values higher than 60-80% were observed. The loss of increment calculated from all sample plots was increasing between 1981 and 1991 in each damage classes. However, the loss of increment decreased in the next two years. It should be born in mind that such an increment loss was calculated for the sample trees of the different damage classes and does not reflect the changes of the whole stand or stands.

1.7. It is generally true that **the increment loss in years** with higher indexes is higher while it is less in years with low indexes. When the environmental factors are favorable for high growth then the healthy trees are growing faster. But when a factor limiting growth appears it has a stronger effect on the healthy trees than on the damaged ones. This is the reason for the virtual contradiction, that higher growth is coupled with higher loss while lower growth is coupled with lower loss.

There were not any relations found between the age and the dimension of the increment loss in the case of the sample trees. The healthy trees grew quite similarly on the sample plots with the same age, but the damaged trees showed considerable differences in the increment losses on the different sample plots.

2. THE RELATION BETWEEN RING WIDTH AND PRECIPITATION

The precipitation has a strong influence on the ring width. Based on the tree ring indexes of healthy trees and the monthly total precipitation, this chapter intends to quantify this effect and identify the months or periods playing an important role in determining the ring width.

2.1. The analysis of the monthly precipitation showed that June and July influenced the growth the most, their effect was between 9-38%, i.e. the precipitation of the given month determined the growth in such extent. March and April followed these months in the rank of importance.

2.2. The total annual precipitation determined the ring width in 9-18%.

2.3. The precipitation of the period between May and July determined the ring width in 13-35% and significant correlation was found in all cases.

2.4. The precipitation of the periods August-October and November-April had no detectable effect on the ring width.

2.5. The precipitation of the vegetation period showed a significant correlation with the ring index. The value of r^2 in this case, similarly to that of the total annual precipitation was 9-18%.

2.6. The weighted total precipitation of Pálfai was found decisive in 18-39%. The highest value was observed in the Szentendre 75H stand showing strong influence on radial growth, the weighted precipitation determined the ring width in more than one third. The weighted indexes of Pálfai were determined for agricultural crops, they may need corrections when used for trees. With a larger number of observations the correlation coefficients of the different months could be better calculated and thus the weighted indexes could be adjusted to the tree growth. On the basis of the current observations the weighted index for March and April should be increased, the index for June should be higher than that of July, and the index for August should be decreased.

2.7. The two- and three-month totals appeared to be decisive in the period of May-July/August, the highest correlation coefficients observed here reached 41-43%.

2.8. The tree ring indexes from the sample plots of Szentendre 75H and 75E showed correlation with several factors and on a very high level of reliability (95%, 99% and even 99,9%). The indexes from sample plots of Pilismarót and Pilisszentkereszt showed less strong correlation with the precipitation.

2.9. The analysis of twenty-year time intervals did not result in obvious tendencies, except the conclusion that the role of the August and September precipitation steadily increased. The 20-year average of the monthly precipitations increased in these two months, while decreased in the others.

3. OTHER STUDIES AND RESULTS

3.1. Sensitivity: the mean sensitivity of five-year periods was very similar for all six sample plots and averaged between 0,22-0,28. These values were less then the 0,37-0,42 from my previous investigations on other areas. The most sensitive intervals occurred between 1960 and 1980, then after 1990. Because of this, and for the sake of the statistically sound sample size, 20 years intervals had to be created, where the period between 1960-1980 formed one interval.

3.2. Correlation between the sample plots: the correlation between the tree ring series of the healthy trees of the sample plots expresses the level of their similarity in terms of ring width. The trees from the Pilismarót plot were found the most different from the others and especially from the trees of Pilisszentkereszt. The differences between the other plots can be explained by the different ages, stand structures and site conditions. Such a correlation can also be analyzed for the indexes, thus eliminating the effect of age. In this case higher correlation was found between those plots which were close to each other, and the link weakened by the distance.

3.3. Autocorrelation: the primary autocorrelation varied between 0,55 and 0,70 for the different sample plots, i.e. the growth of the previous year influenced the actual growth according to the square of this value.

In case of Pomáz, Szendehely and Szentendre 77E the autocorrelation existed for 3-4 years, or by other words, the growth of a given year was influenced by the previous 3-4 years. The autocorrelation curves of the other plots interestingly do not follow the general rule of the weakening correlation by the widening time horizon, but after a decrease in a number of consecutive years show a strong increase in 1988 then the correlation starts decreasing again. The curve from the Pilisszentkereszt plot shows an alternation with decreasing amplitude, instead of an asymptotic development towards zero. According to the literature, higher-level correlations can remain positive or can even increase under the influence of changes with even frequency.

3.4. Characteristics of years with extremely low growth, i.e. event years: The years of 1962, 1968, 1974, 1990 and 1993 represented minimum extremes both in tree ring and index series for each plots and sample trees. This phenomenon can be explained by several factors, but because the sample plots are found in a considerable distance from each other and the extreme low growth occurred in one single year, the number of possible factors can be restricted to those with climatic and epidemic origin. The precipitation of the vegetation period was very low in 1962, 1968, 1990 and 1993, and it was low in the preceding years as well. The accumulation of the precipitation deficit of 1990-93 should also be mentioned in this context. In 1962 and 1968 however, the deficit was not significant enough to explain such a general and considerable decrease of radial growth. But according to the literature, 1962-63 was the time of one of the most intensive Geometridae gradation. The loss of radial growth could be partly explained by this intense damage. Geometridae and leaf roller damage was observed in 1968 as well, but the cause-effect relationship was not so obvious in this case. The Geometridae also caused considerable damages in 1974, but the extent of the damage was less than in 1962. The year of 1962 is unique, because the with the exception of Szentendre 77E the tree ring curves of those sample trees which later remained healthy separated from those which later showed damage class 2 symptoms of oak decline.

It was only in 1974 when the amount of precipitation could not explain the decreased growth. If we accept the statement on the importance of the precipitation of the May-July period and that of June and July, i.e. these periods are the most decisive ones for the ring width, then the low precipitation of these periods can explain the low growth. This explanation worked very well in case of the Szentendre plot. In Pomáz and Pilismarót there were no single factors with sufficiently high coefficients that could solely explain the reduced growth, so factors other than precipitation could play a role. Factors like low temperature or late frosts could neither be the reasons. The literature mentions several cases where the available information was not enough to explain the occurrence of event years.

The joint effect of low precipitation and caterpillar attacks could be an obvious reason for the event years, but these years are strikingly corresponding with other Hungarian and with some foreign oak chronologies, and they were also found in some German and Swiss spruce and beech studies. Although the occurrence of the event years is characteristic to the tree-species, the effect of weather extremes is universal. However two conclusions can be drawn from the above considerations:

3.5. The event years of 1962, 1968 and 1974 can well be used as starting points of the synchronization in case of tree ring analysis for Quercus petreae on free-draining sites in Hungary.

3.6. The explanation for the event years should be searched for in larger areas than the Pilis mountains. The main reason is likely to be found in the climate, insect gradations should be seen as contributing factors. Further analysis in cooperation with forest protection experts is needed to clarify the connection between dry periods and insect gradations. It is obvious and well known that dry and warm years can accelerate the multiplication of biotic agents, which can cause damages in different stands and remote locations.

3.7. Event years can be of positive extremes as well, however these positive event years did not show a clear picture. 1975 was found most frequently in Pilismarót, Pilisszentkereszt and the two plots in Szentendre. Although the annual precipitation was quite normal in this year, it was quite high in the vegetation period, the May-July period and the weighted total were also higher by about 25-35%.

Through analyzing tree rings from sample plots affected by oak decline, this paper presented a method and its multiple use, which enables us to detect trees and stands in weakened condition, thus identifying sources of potential danger. Although the oak decline is not mentioned so frequently as before, this does not mean that the health condition of the sessile oak is not problematic anymore. There are not so many new cases reported and the number of dying trees is not so strikingly high, but the loss of increment is still considerable, which results in a loss of income for the forest owners and managers even if not always recognized.

Now we see, that the weakened health condition of the oak trees could have been detected much earlier by studying the changes of radial growth. Such kind of damages can occur on the oaks or on any other tree-species at any time in the future. Growing conditions of the recent years can well be analyzed with the above method, and predisposed condition, deterioration or damage of certain tree-species can be identified even on a country-wide scale in due time.

With such a method the predisposed condition or the damage itself can be detected well before the appearance of the visible symptoms. This can help the forest research in identifying the causes of the damage.

The method presented in this paper can directly assist forest management by identifying other damages, such as the drought. The several relations between ring width and the environmental factors can help forest ecology, and the results can contribute to defining future research directions by identifying new areas and parameters.

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