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Mean growth behaviour of forest stands – Methodological aspects from dendrochronology and forest mensuration

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Situation and Motivation

The development of mean index chronologies is a basic topic of dendrochronolology. Commonly this procedure consists of prewhitening, trend estimation and index calculation of each individual series. Finally, all single index series have to be aggregated to the mean index series. Application of the arithmetic mean may be disadvantageous because all index values have the same weight, and outliers may distort the mean. For this reason so far Tukey's biweight robust mean (Weisstein, 1999-2007) is mostly used for calculation of mean index values. The effect of applying Tukey's biweight motivates the following analyses and alternative proposals. A chronology of common beech from Schleswig-Holstein in northern Germany (Fig. 1) will be used as an example.

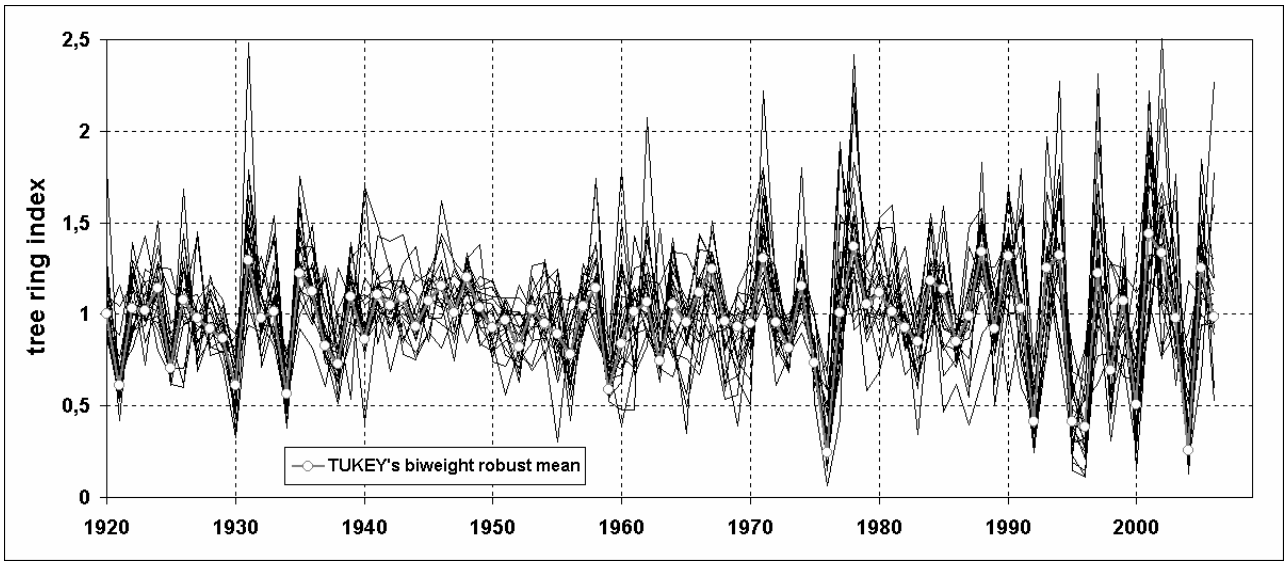

Figure 1: Index chronology Bornhoeved, common beech; 20 dominant sample trees

Tukey's biweight uses a weight function. The absolute weight values of the function increase with growing distance from the mean index, but drop down quickly when the distance from mean exceeds a certain threshold value (Fig. 2). Values beyond these thresholds do not influence the mean, because their weights are close to zero. This basic pattern may be traced at each time step. As additional examples, the years 1960 and 2000 were chosen (Fig. 3 and 4), and the tree numbers of the values are indicated which were excluded by Tukey's biweight from the calculation of the mean. Comparing the figures 2, 3 and 4 (1920, 1960, 2000) it is conspicuous that the tree numbers (individual series) which are excluded from the calculation of the mean calculation by the weight function of Tukey's biweight change from year to year.

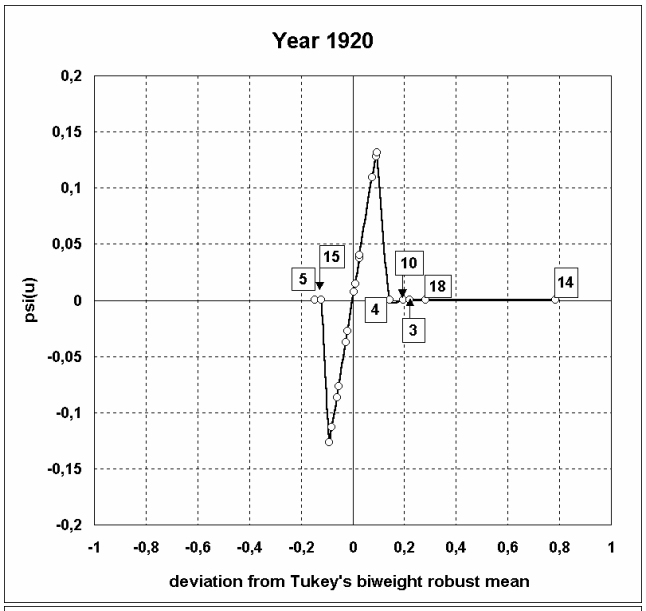

Figure 2: Values of the weight function psi(u) in relation to the deviation of the tree individual index values from the mean; example: year 1920; Numbers of individual series (=sample trees) which do not contribute to the mean index due to their weight values close to zero are indicated with boxes.

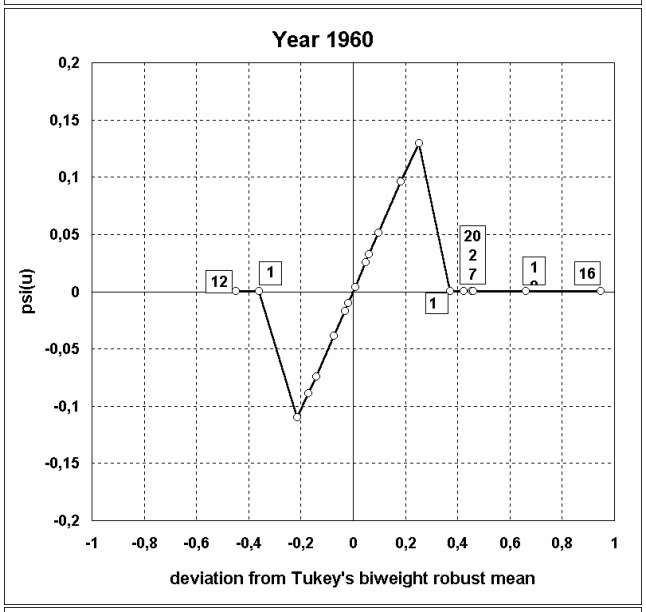

Figure 3: Values of the weight function psi(u) in relation to the deviation of the tree individual series index values from the mean; example: year 1960; Numbers of individual series (=sample trees) which do not contribute to the mean index due to their weight values close to zero are indicated with boxes.

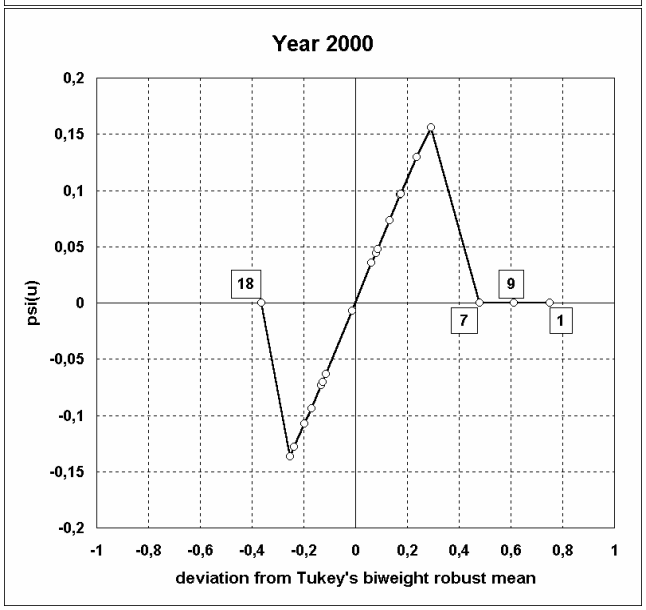

Figure 4: Values of the weight function psi(u) in relation to the deviation of the tree individual series index values from the mean; example: year 2000; Numbers of individual series (=sample trees) which do not contribute to the mean index due to their weight values close to zero are indicated with boxes.

This indicates that the same series, which is selected to contribute to the mean index chronology at a certain year, may be rejected at another year. Such effects of a mathematical procedure cause problems concerning its general acceptance. It seems to be necessary to evaluate quality and suitability of each single series with respect to their contribution to the mean index series. Each selected individual series should express the typical behaviour of the investigated tree population.

A first proposal for an alternative approach

A first alternative approach which evaluates single series starts from already prewhitened and detrended individual index series. It includes the following steps:

(1) Calculation of the chronologies‘ signal strength:

$$\hat{S} = \frac{n(n-1)}{2} \cdot \sum_{i<j} cor\left(I^i, I^j\right)$$

and the signal-to-noise ratio: $SNR = \frac{n \cdot r_m}{1 - r_m}$.

(2) Calculation of the signal strength of each series:

$$S_k = \frac{1}{n-1} \cdot \sum_{j \neq k} cor\left(I^k, I^j\right).$$

The signal strength of a single series S_k may be measured as the mean correlation to all other series of the chronology. Therefore S_k may be tested for significance. Series with negative or non-significant S_k are rejected from the chronology building. The procedure returns to step (1) until all remaining series are significant.

(3) Calculation of the mean index chronology according to Neumann (2001):
This calculation is based on the assumption that index series showing more stand-typical patterns have a smaller share of error and thus a higher signal strength than those with stand-untypical patterns. Obviously, it may be concluded that individual index series may be weight by their signal strength for calculation of the mean index chronology:

$$C_t = \frac{1}{\sum_i S_i} \cdot \sum_{i=1}^{n} S_i \cdot I_t^i \; ; \qquad t=1, \ldots, s.$$

For illustrating the effects of this alternative procedure, a chronology of a mature pine stand (Grunewald, Berlin forests; n=30) was chosen (Fig. 5 to 8).

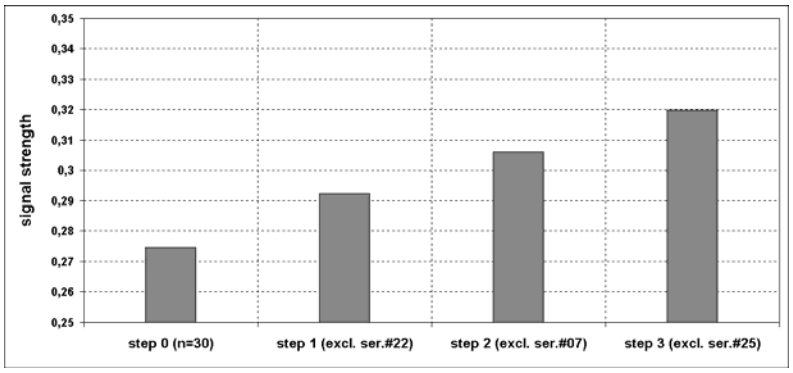

Figure 5: Increase of chronology's signal strength by stepwise exclusion of individual series with non-significant signal strength.

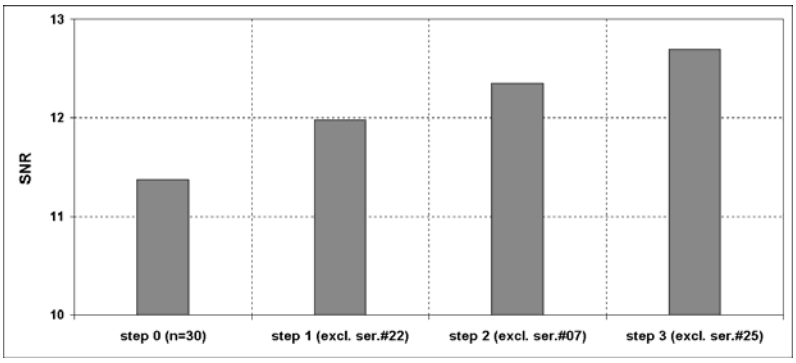

Figure 6: Increase of signal-to-noise ratio.

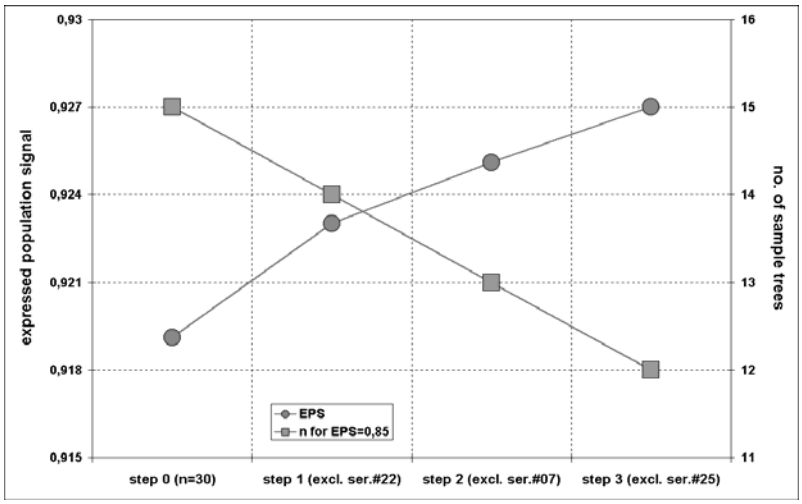

Figure 7: Increase of expressed population signal EPS and decrease of required sample size to get EPS=0,85.

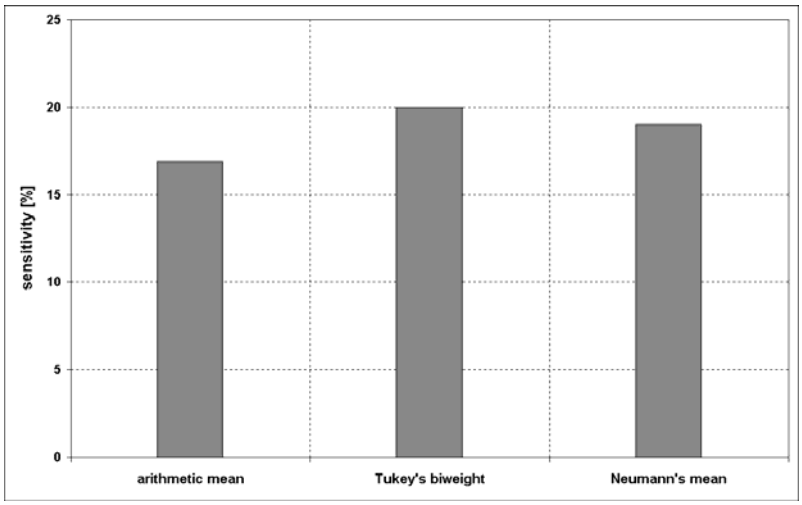

Figure 8: Comparison of mean sensitivity of the mean index series when using different calculations of mean.

Evaluating these results, the following conclusions can be drawn:

i. Identification of series with negative or non-significant mean cross correlation to the other series and their subsequent exclusion from calculation of mean index may improve mean signal strength of the whole chronology.
ii. Simultaneously, SNR and EPS increase and required sample size decreases. The mean sensitivity as a characteristic of the climate impact is higher if the alternative approach together with Neumann's mean is used other than by the application of the arithmetic mean, but sometimes lower than by application of Tukey's biweight. The latter is due to the enhancement of the centre of the actual distribution per year.
iii. The "cleaning" of a noisy chronology by the alternative procedure is done by exclusion of entire series but never by exclusion of index values only at a certain year.

A second proposal to get a stand-typical mean chronology

Taking increment cores to develop mean index chronologies for the investigation of climate growth relationships may be seen as only one special branch of tree ring research. Tree ring series may be used for a more comprehensive growth behaviour analysis of a forest stand if they cover the whole life span of the stand. Growth behaviour analysis aims at the reconstruction of the mean growth course of a stand, represented by the dominant trees, and at the evaluation of their characteristics in the temporal course. Growth courses of individual trees can be compared and evaluated appropriately by their diameter growth course. The measured ring widths have to be cumulated to get the diameter growth course from increment cores. However, we are often faced with the difficulty that the pith of the tree was failed. We do not dispose of measured data of tree's diameter below the place where the first tree ring border is visible. However in many cases a circular arc of the first visible ring can be used to estimate the diameter of the inner part of the stem (Fig. 9).

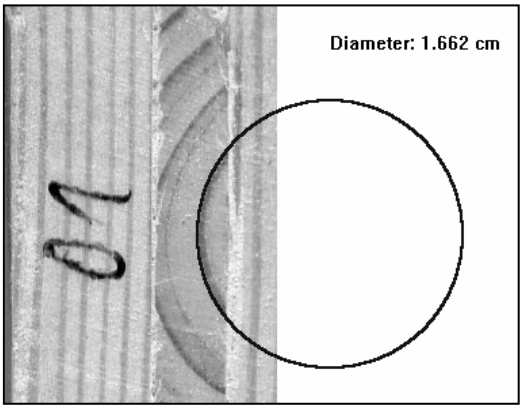

Figure 9: Determination of the inner portion of tree's diameter which was failed while coring; The inner part of the sanded core was scanned. Calculation of the inner diameter is done with the help of a computer program which uses geometrical and graphical methods.

This inner diameter (*ID*) can be used as initial value for the summation of all doubled ring widths to get the stem's diameter without bark. But even if the pith is hit, the summing up will never result in the exact diameter without bark of the tree. This is due to:

i. The shrinkage of the increment core while drying;
ii. The tree ring series obtained by the increment core is only one random realisation of the growth course of the tree. There are theoretically infinite places at breast height of a tree to take increment cores. The extraction of two increment cores in orthogonal position at breast height may not really represent the true shape of the cross section of the tree and therefore the estimation of the radial increment of the tree is hindered. It is strongly recommended to measure exact ring widths (rectangular, i.e. shortest, distances between adjacent ring borders).

The problem may easily be solved by following the assumption that the appropriateness of ring widths within time series is kept independent from the exact place of boring. The diameter of the stem without bark (DBH_{wB}) may be determined from measured values of diameter including bark and withdrawal of double bark thickness obtained from a suitable bark function. If the appropriateness of ring widths (*RW*) within time series is accepted as the most important criterion of growth behaviour, the absolute values may be transformed by correction factors (*CF*) very easily:

$$CF = \frac{DBH_{wB}}{ID + 2 \cdot \sum_{t=1}^{n} RW_t}.$$

In that way one can obtain the chronology of the corrected absolute diameter time series (Fig. 10).

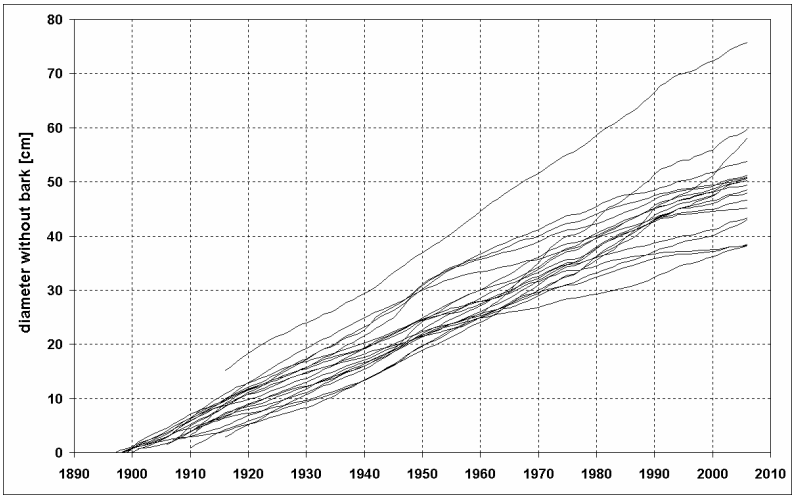

Figure 10: Absolute diameter growth courses of 20 dominant beeches. Identification of outliers concerning growth dynamics is hard to perform.

As an example for illustration of the methodical conclusions the chronology of Bornhoeved (common beech) is used again. By calculation of relative growth courses (all diameter values of a time series are set relative to the final DBH at the end of the series) a better comparison between the series is enabled (Fig. 11).

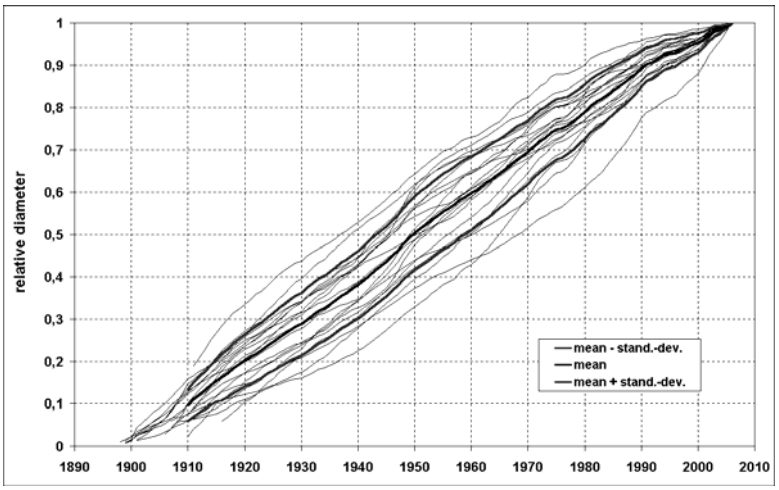

Figure 11: Relative growth courses of the 20 sample trees together with mean +/- standard deviation. Outliers concerning growth dynamics can easily be identified.

Evaluation of the similarities between the series and of the suitability of a individual series using the relation to the stand-typical pattern is eased by the comparison with the mean relative curve and the range between mean +/- standard deviation, respectively. So, outliers concerning stand-typical growth dynamics can be reliably identified and can be excluded from the calculation of the mean curve (Fig. 12).

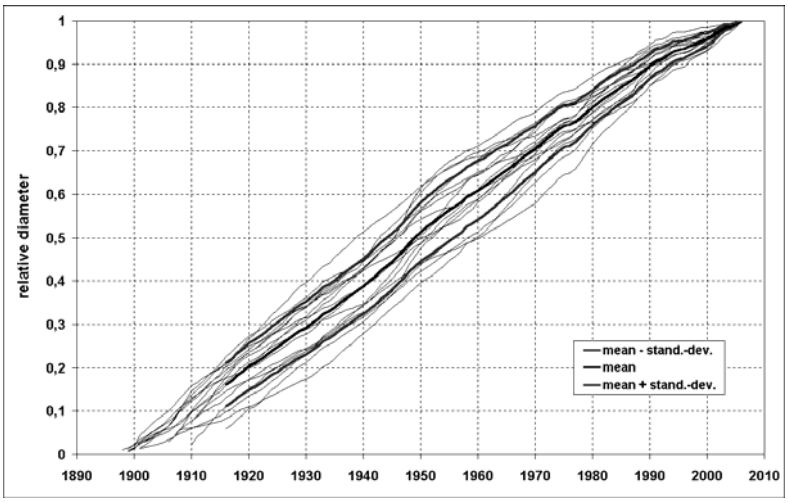

Figure 12: Relative growth courses of 17 sample trees together with mean +/- standard deviation. Sample trees 5, 7 and 19 were excluded as outliers. The stand-typical growth pattern emerges more clearly.

The plot of the included absolute diameter series of the chronology together with the identified outliers (sample trees 5, 7 and 19) shows that these series do not really fit to the common stand-typical growth pattern, especially after 1970 (fig. 13).

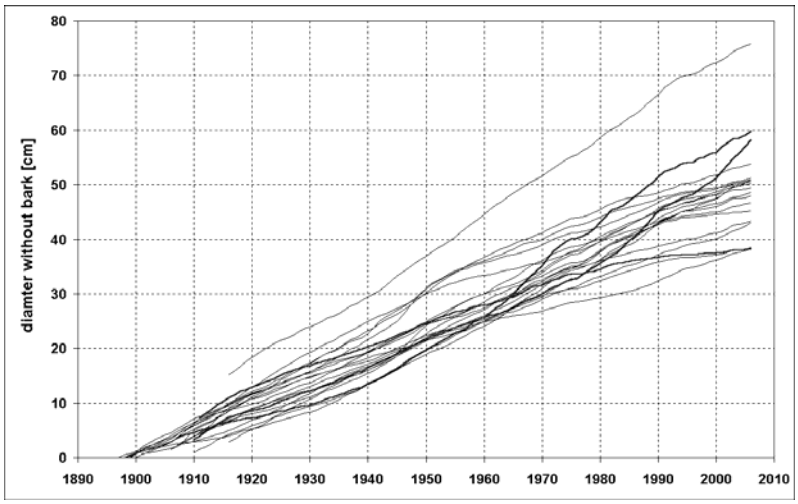

Figure 13: Absolute diameter growth of the included trees of the chronology together with the excluded sample trees 5, 7 and 19 (fat lines).

The remaining steps to get the mean index chronology are easily to perform. The time series of the mean relative diameter growth course forms the basis of the calculation. Mean absolute diameter of all included sample trees is obtained by the calculation of weighted means of the basal areas. Time series of mean diameter DBH_t may be obtained by multiplication of mean relative diameter course with mean absolute diameter. Time series of mean ring width has to be calculated as differences from mean absolute diameter course DBH_t.

$$RW_t = \frac{DBH_t - DBH_{t-1}}{2}.$$

Prewhitening, trend estimation, trend elimination and indexation may be done in one of the many known ways, according to the conviction, intention or taste of the dendro-colleague.

Summary

Beginning with the established method of mean index series calculation by Tukey' biweight robust mean, its disadvantages and inconsistency are discussed as well as two alternative procedures are presented.

Statistical analysis of the contribution of a individual series to the mean series and the decision upon its inclusion or exclusion from the mean calculation on the basis of entire series is proved to be an adequate procedure. The weighting of single series by their signal strength to calculate the mean index chronology (Neumann, 2001) seems to be more appropriate than the distance from the centre of the index-distribution at a certain year.

Derivation of the typical stand-wide diameter growth enables a comprehensive growth behaviour analysis. Central to the procedure is the calculation of relative diameter growth courses. By this transformation, outliers can be reliably discovered. From the mean diameter time series one can obtain transformed series of basal area, basal area increment and radial increment. These series may be verified and investigated in many directions such as homogeneity of growth course or structural breaks, autocorrelation of first and higher order, relations between sensitivity and autocorrelation, pointer year analysis and more. Back-transformation to mean ring width series is done by differentiating of mean absolute diameter series. Derivation of mean index series from mean ring width series follows well known procedures which are in common use. All steps are based upon a unified data pool procedure.

References:

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