# Zum Einfluss der Witterung auf Wuchsverhalten und Vitalität der Trauben-Eiche (*Quercus petraea* [MATT.] LIEBL.)

Habilitationsschrift

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## Inhaltsverzeichnis

## Summary

"On the influence of climate on growth and crown vitality of Sessile oak (*Quercus petraea* [MATT.] LIEBL.)"

**– Objectives –**

Sessile oak (*Quercus petraea* [MATT.] LIEBL.) is an ecologically as well as economically important tree species in the northeastern lowlands of Germany, especially in the regions where climate is more continental. The widespread introduction of the species into mature Scots pine (*Pinus sylvestris* L.) stands as a means of ecological forest conversion has further enhanced its relevance in forest science and management. For a few decades, however, an increased number of trees and stands showing a severe decline in vitality has led to critical discussions on the possible role of oaks in today's forest development strategies. The adaptive capacity of Sessile oak will be further challenged by climate change conditions in the future. In this context, more information is needed on the relations between the vitality status and growth, including the development of these relations in the next decades.

The study investigates the dependencies between annual radial increment in *Quercus petraea* (measured as tree-ring width, TRW) and individual-tree vitality as well as the effects of climatic variables on TRW on different temporal scales. Retrospective analyses of the climate-growth system will be used to model the future behavior of trees under regional conditions, thus contributing to estimate more exactly the risks associated with the promotion of Sessile oak as one of the central species in forest conversion in Brandenburg. This central objective shall be accomplished by analyzing the following research questions:

(a) Which results can be obtained by applying two different approaches to quantify individual crown vitality, and how are they related to the radial increment of trees?
(b) Which relations may be determined between climatic variables and annual radial increment? Are these relations stable or do they change over time?
(c) What is the outcome of the analyses with respect to the future role of Sessile oak in forest planning and management in northeastern Germany?

**– State of knowledge –**

The central term "vitality" can be defined in different ways. On the one hand, vitality is understood as the ability of an organism to actively utilize available resources and to expand its sphere of influence. On the other hand, it is seen as a rather passive capacity to maintain the basic life functions, even under stressful conditions. This ambiguity in definitions may also be observed in literature on other important ecological concepts such as resilience, stability, and elasticity of organisms and ecosystems. From a more general point of view, vulnerability analyses are increasingly applied as a conceptual framework to study the climate change effects on forest structure and functions. They compare the "impact" of external influences (as a result of sensitivity and exposition) to the adaptive capacity of a

system in order to effectively assess the actual extent of its vulnerability. Additionally, this concept can integrate natural as well as cultural, social, and political influences.

The vitality of forest trees cannot be quantified directly but should rather be assessed by defined procedures and guidelines. The European standard procedure to evaluate crown transparency on Level-II-monitoring plots is used in this study as an approach to estimate vitality individually in oaks. The results of this approach are compared to an alternative method of classifying crown structure based on branching patterns and presence of twigs.

According to the annual assessments of crown condition, oaks have been the species with the highest degrees of crown transparency in Brandenburg throughout the past two decades. This has been accompanied by an unusually high level of severe defoliation, crown dieback, and individual mortality in some regions. The decrease in vitality has been attributed to the single or combined effects of abiotic (climatic extremes, site variables, water deficiency) and biotic factors (insect defoliation, pathogenic fungi)

The annual increment rate as expressed in the tree-ring width (TRW) is commonly regarded a reliable indicator of tree vitality. While absolute amounts of TRW mirror the individual site and competition status, inter-annual differences are indicators of climatic influences. Statistical properties such as auto-correlation and sensitivity may be computed for time series of TRW and tree-ring index (TRI). "Pointer years" with conspicuously high or low TRW in a large proportion of the sampled trees give further information on years with extreme climate conditions. To analyze the stochastic dependencies between TRI and climate, a wide range of dendroclimatic and dendroecological methods have been developed. These models use climatic data in either monthly or daily resolution. By extrapolating the historical climate-growth-relations as determined by retrospective analyses, they allow estimations of the reactions of TRW to scenario data under the influence of climate change.

**– Material –**

Investigations were carried out using two sets of trial plots. The *core plot* sequence K1-K5 comprises five mature mixed stands of Sessile oak with Scots pine along a gradient from Saxony-Anhalt to eastern Poland. The trees are 110-150 years old and grow under conditions characterized by sandy and partly podsolic cambisols with average water supply. To complement this sequence, a set of 20 *additional plots* was established in mixed oak-pine stands in Brandenburg on comparable sites as well as on more favorable and more detrimental soil types. Tree ages on these plots range from 35-160 years. In addition to the usual growth and yield data for the whole plot, increment cores were extracted from a representative sample of 20 dominant and 20 suppressed trees on each core plot and from 20 dominant trees on each additional plot. Time series data of local climate (daily mean temperatures and daily precipitation sum) were provided by the Potsdam-Institute for Climate Impact Research ("PIK") as part of their contribution to the research projects "OakChain" and "INKA BB". Data for the years 2007-2060 come from the median scenario of the regional climate model "STAR 2" which is based on the SRES-scenario A1B and assumes an increase in temperature of two Kelvin until 2060 (as compared to the 1961-1990 average).

**– Methods –**

Individual vitality was recorded on the core plots (i) according to the European standard method for the assessment of crown condition based on defoliation percentages in summer (EICHHORN et al. 2006) and (ii) following the approach proposed by KÖRVER et al. (1999) for crown structure classification in winter. Both methods were applied for all dominant and co-dominant oaks in the five subsequent years from 2006 to 2011. Oaks on the additional plots were assessed only once.

Two increment cores per tree were dried, mounted on wooden supports, and sanded to obtain smooth surfaces. The measuring table "LINTAB 5" was used to determine annual earlywood and latewood width values which were later added to obtain TRW time series. In the process of data preparation, trees with unusual DBH growth curves were excluded from further analysis. The program "CLIMTREG" (BECK et al. 2013) was applied to eliminate long-term trends in individual TRW series by means of cubic spline functions and to minimize auto-correlation within the resulting TRI time series. Plot-specific "chronologies" were calculated as the arithmetic mean of individual TRI time series, while mean TRW series served as a basis to determine auto-correlation and sensitivity values. These parameters were computed both for the complete time span covered by the TRW series and for moving 21 year intervals along this time span ("moving windows"). On the core plots, separate TRW parameters and separate chronologies were derived for the dominant as well as suppressed trees. Pointer years were identified on the basis of the mean and standard deviation of annual TRI distributions.

To analyze the relations between climate and growth, the programs CLIMTREG and "`bootRes`" for `R` (ZANG & BIONDI 2012) were applied. The algorithms combined climate data from stations located close to the respective plots and the chronologies as determined by CLIMTREG. The `bootRes` package calculates correlation coefficients as well as response functions between monthly temperature (or precipitation) and TRI values in fixed time spans or, alternatively, in moving windows. Statistical significance is estimated on the basis of the 95-%-confidence intervals resulting from the "bootstrapped" determination of the respective coefficients. CLIMTREG was applied to identify the exact periods exhibiting the strongest correlations between TRI and daily precipitation or temperature. The program achieves this by total enumeration of all possible periods ranging in length from 21 days to 183 days in the period from July 1 in the previous year to October 31 in the current year. The variables found by this method were processed in Primary Component Analyses (PCA) with subsequent Primary Component Regressions (PCR) to obtain a model which allows estimations to study the behavior of the trees under climatic conditions according to the local scenario.

**– Results –**

Regarding the research questions formulated above, the results of the various investigations may be summarized as follows:

(a) Crown condition and growth

During the investigation interval 2006-2011, crown condition as expressed in summer foliage as well as in crown structure has improved considerably. While long-term influences on crown condition which span several years are mirrored in the crown structure, defoliation percentages represent mostly short-term effects on the annual level. Therefore, the results of the different assessment methods cannot be seen as representative of each other, but rather as complementary information on different aspects of individual vitality. Positive rank correlation coefficients between the two parameters are statistically significant on all core plots. Crown structure values are correlated more closely to individual basal area increment than defoliation percentages. At the same DBH, trees with larger crowns have a significantly better crown structure and less defoliation.

Annual radial increment has been increasing on the core plots over the past decades, resulting in linear to convex DBH curves. The increment level of the dominant trees is on average slightly higher than that of the first yield class in the table for oak by ERTELD (1963). On the additional plots, mean TRW is more or less comparable to yield table values but shows a slowly decreasing trend in a number of stands. The two core plots located in Poland exhibited the highest radial increments 2006-2011, both absolutely and relatively. Regarding the plots in Germany, increments were higher on K2 (southern Brandenburg) in comparison to K1 and K3.

(b) Climate-growth relations

On the annual level, TRI time series are correlated more closely to precipitation sums than to annual mean temperatures. The relations between annual values of the drought index after DE MARTONNE (1926) and TRI show the same pattern as those between TRI and precipitation sums. Except for one of the additional plots, the respective correlation coefficients are statistically insignificant. Correlations did not increase when designated climate parameters were calculated exclusively for the vegetation period instead of the whole year.

Dendroclimatological relations on the monthly scale were analyzed with `bootRes` (i) for the common interval ("CIN") covered by both climate and increment data (1951-2006) and (ii) for the first and the second half of this interval separately. Trees on the core plots K1 and K3 respond almost similarly to climatic influences: High TRI values are related to above-average precipitation mainly during the winter months, as well as in late summer and early fall of the year of growth. On the other core plots, the dependencies are less clear but indicate a similar importance of precipitation in July, August, and December of the year prior to growth. The relations of TRI to monthly temperature are weaker than those to precipitation with the same ranking of plots regarding their sensitivity. The most favorable influence on TRI is exerted by the cool spring to early summer months in the year of growth as well as the less significant above-average temperatures in December. Correlation patterns are very similar for both dominant and suppressed trees. The additional plots support the general findings of the German core plots.

The complementary effects of temperature and precipitation are expressed in the opposite direction of their correlations with TRI in certain months: while most of the temperature coefficients were significantly positive for the spring and summer months, nearly all precipitation coefficients are negative. Separate analyses of the first and the last half of the CIN show that the strength of correlations between TRI and climatic variables has been increasing over the past decades. This is evident especially for K1 and K4, but also for K2. When summarized over all plots, there were distinctly more significant correlation coefficients in the period from 1984-2006 than from 1951-1983. Additionally, the percentages of negative coefficients for temperature and positive coefficients for precipitation have increased when comparing the first and second periods.

According to analysis of the relations of TRI to climate data in daily resolution with CLIMTREG, high summer precipitation in the preceding year clearly promotes above-average TRI values. Another conspicuous climate-influenced time period ranges from late November to February with positive correlations both to precipitation and to temperature (at least partly). The third important period for TRI in most trees on the core plots starts in early April and lasts until Mid-July. During this time, high TRI values are correlated with low temperatures and high precipitation.

The behavior of the climate-growth system under future conditions was estimated by models for TRI development generated in CLIMTREG on the basis of different calibration periods. In reference to most of the considered plots, the average TRI is higher if the second half of the CIN is used for calibration rather than the entire CIN (or its first half). The results of the different models (or rather, of the different calibration periods) do not differ very much in terms of the identified variables (i.e. length of influential period and type of climatic parameter). However, the direction of correlations becomes more variable in the last half of the CIN, indicating changing relations between growth and climate.

(c) Conclusions for the future of Sessile oak in northeastern Germany

The results of this study may be summarized in a number of risks, but also of opportunities regarding future vitality and growth of Sessile oak under regional conditions. Finally, there are some options that can be recommended for the silvicultural management of the species.

The *risks* are related to those findings that point towards an increasing influence of external influences or rather climatic variables on tree growth. This increase is visible for example in the higher number of significant correlation coefficients calculated between monthly climate and TRI in the decades close to the present, compared to the decades following the middle of the past century. The decrease in average auto-correlation within TRW time series is another indicator of this development. STAR 2 as well as other regional climate models predict more frequent and more intense drought periods in northeastern Germany. With respect to these scenarios, the positive correlations between TRI and precipitation identified by the applied dendroclimatological methods suggest a higher risk of severe drought stress in the future. This could negatively affect both the vitality and growth of trees.

The complex interactions of climatic extremes with other stress factors such as insects or pathogenic fungi make it difficult to estimate the extent of adaptive capacity on the individual, forest stand, or species level. Weak vitality and increased mortality rate can be expected especially on dry and poor sites or in dense stands with small crowns that are detrimental to individual vitality. Risks that cannot be calculated result from (i) unpredictable behavior of the climatic system after so-called "tipping points" have been passed; (ii) extreme climatic events such as storms, fires, or unprecedented drought stress; or (iii) damages caused by invasive species or established species that benefit greatly from climate change.

*Opportunities* for Sessile oak can be seen in the adaptive processes that were detected in the climate-growth relations by means of CLIMTREG analysis. Additionally, the more or less constant number and intensity of pointer years in the stands, along with the stable degree of sensitivity in TRW time series, support the assumption that despite rising temperatures, tree growth has remained basically unchanged. Most trees did not show any severe reaction to the extreme drought situation in the summer of 2003. The improvement of crown condition on all core plots after 2006, the high genetic diversity of the species in general and of the trees on the core plots, as well as the weak reaction to 2003 combined suggest a strong adaptive capacity that will not be exceed permanently until the end of the scenario period (2060). Although individual trees may continue to suffer and die off on a local scale, the probability of a rapid increase in trees with decline symptoms is considered very low. A high elasticity of the species can be expected especially in regions where chronologies show minor correlations to climate parameters and on sites with above-average water availability.

Management *options* to support Sessile oak vitality and growth consist basically in promoting favorable conditions and limiting negative influences. A large crown with dense foliage and a well-developed root system are crucial conditions for individual vitality which should be strengthened by suitable silvicultural strategies as in reducing stand densities at an early age. Mixed stands have a higher stability towards disturbances and provide more diverse habitats for natural antagonists against defoliators. The relatively weak competitiveness of oaks should be taken into account when advocating mixed stands. Regeneration activities should enhance genetic diversity, promote phenotypes with above-average vitality, and accelerate the adaptation of the species by "assisted migration" of drought-tolerant provenances. Competition for water may be eased by lower stand densities. However, the canopy should be kept sufficiently closed to prevent an excessive growth of ground vegetation. An adapted system to monitor forest growth and vitality should support the proposed management of the species. This could be used to technically assist the natural capacities of the species in counteracting major insect outbreaks and other severe biotic risks as early as possible.

In conclusion, there are not only reasons to worry, but also reasons for optimism regarding the future of *Quercus petraea* in the study region. A silvicultural regime following the overall objective of high individual and stand vitality, management techniques that reflect the specific site conditions, a suitable forest monitoring system, and a large proportion of mixed stands with rich structural diversity are important preconditions for the successful development of the species. At the same time, a thorough discussion between all stakeholders, interest groups, and the public is needed on the social and political role of forests and the required level of management. This should lead to a stable appreciation of forestry providing the resources and staff necessary to cope with the consequences of climate change which should not only be limited to northeastern Germany.