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# Temporal Variations in Tree-Ring Growth Response to Climate of European Larch (*Larix Decidua* Mill.): An Example from Sudetes, Poland

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**Abstract.** The temporal stability of climate–growth relationship is a basic assumption and requirement of climate reconstruction using tree rings. However, many recent studies showed change in tree-ring growth response to climate for the last decades. The temporal stability of relationship mentioned above can depend on the local factors, e.g. slope aspect. In presented study the tree-ring growth response to climate of larch from Polish part of Sudetes was analysed over time. The aim was to investigate its temporal variability, existence of trends and influence of local factors. The relation between tree-ring growth of larches from six sites located at comparable altitudes (about 700-750 m.a.s.l.) and climatic factors that mainly control the tree-ring growth of larches in the study area was analysed over time. The Pearson correlation between tree-ring width site chronologies and climatic data for the study area (the average monthly air temperature and total monthly precipitation series from high-resolution gridded dataset CRU TS v.4.01) was calculated in 40-years moving windows for the period 1901–2010. The results showed variations in the tree-ring growth response to climate over the analysed time period. Although in general, similar trends were observed for all sites, some differences in trends and magnitudes among sites were also spotted. Interesting is, that the response of sites became more consistent and similar for the last decades. The discussion of the received results with respect to currently observed climatic trends in the region and local factors that can explain the differences in response between particular sites is presented.

## 1. Introduction.

The temporal stability of climate–growth relationship is a basic assumption and requirement of climate reconstruction using tree rings. However, many recent studies showed change in tree-ring growth response to climate for the last decades [1]. The temporal stability of relationship mentioned above can depend on the local factors, e.g. slope aspect [2-4]. In presented study the tree-ring growth response to climate of larch from six sites located in Polish part of Sudetes was analysed over time. The aim was to investigate the temporal variability of above mentioned relation, existence of trends and influence of local factors.



## 2. Materials and methods.

Six sites located in Sudetes Mountains were selected for this study. Sites were located in the three parts (mountain ranges) that belong to the Sudetes: Karkonosze (sites 1-4), Jizera Mountains (site 5) and Stone Mountains (site 6). All of them were located at similar altitudes, from 709 to 752 m a.s.l. Among the sites three were located at slopes with northern aspect (site 2 and 5 – N-NW, site 3 – NE), two had southern location (site 1 – SW, site 6 – S-SSE). One site was located near the summit (site 4). Tree stands with larches of similar age, more than 100 years old, were chosen. In each site 17 to 20 trees were sampled. The measured tree-ring widths series of trees from particular sites were used to build site chronologies. This process was done with similar procedures as described in [5]. In the next stage of analysis, the residual versions of created chronologies commonly used in this kind of studies, which preserve mostly high frequency variability, were used (compare [6]).

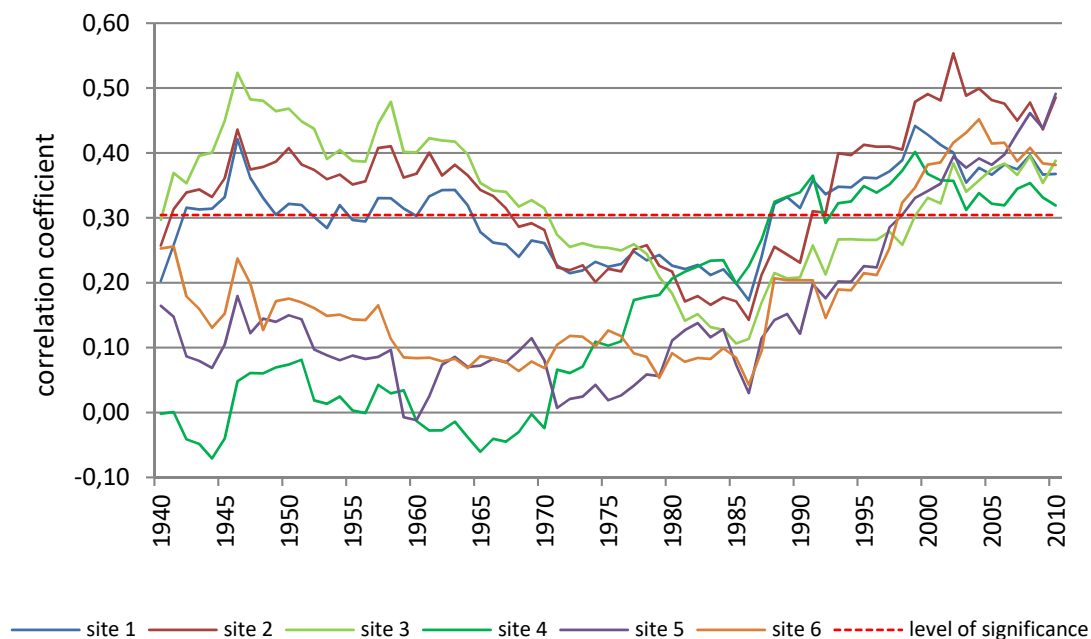
Climate-growth relationship analysis for larch in Sudetes showed that its growth in this area is mainly associated with climatic conditions of summer of the year preceding the tree-ring formation and temperature of May of the year in which the tree ring is formed. These variables were taken to the analysis which results are presented here. The Pearson correlation coefficient between site chronologies and climatic variables (average monthly temperature and total monthly precipitation) was calculated in 40-years moving windows, for the period 1901–2010. The climatic data were taken from high-resolution gridded dataset CRU TS v.4.01, made in  $0.5^\circ \times 0.5^\circ$  grid network [7]. The period of the analysis was limited by the time span of gridded data (1901 – 2016) and the chronologies (common period for all chronologies span the years 1894-2010).

## 3. Results.

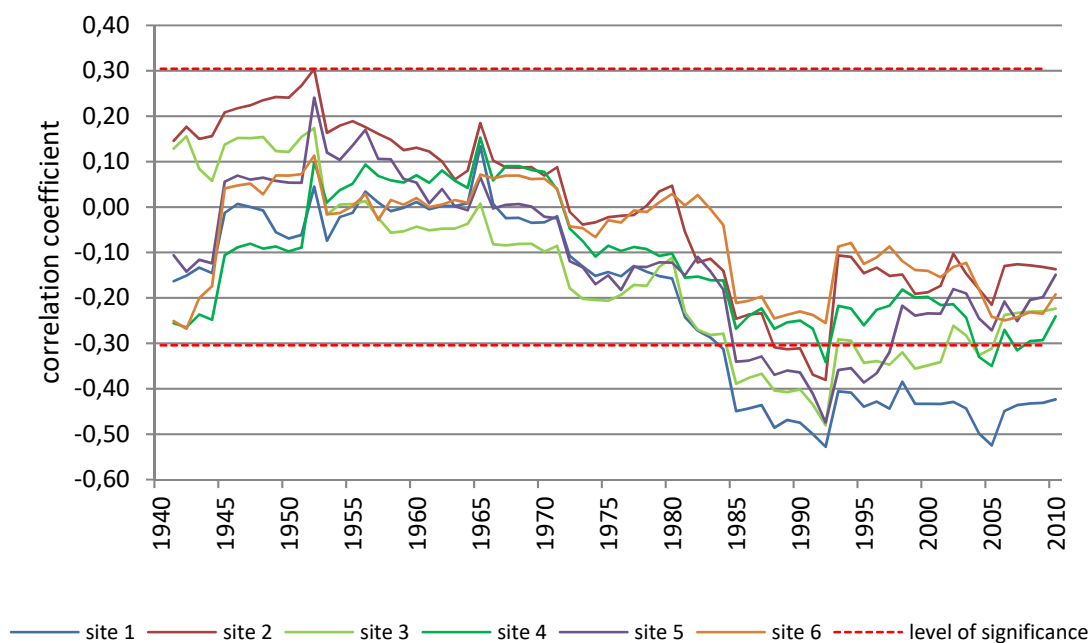
The results of the analysis show variations in tree-ring growth response of larches to climatic conditions over the analysed time period. Also a difference in response between particular sites was observed. In Figure 1, which presents the results obtained for May temperature, two groups of chronologies can be distinguished. The first consist of the highest sites (sites 1, 2 and 3; 726-752 m a.s.l.). For this group the positive, significant correlation values were recorded for the first (since the second part of the 1940s till the second part of the 1960s) and last (since the second part of the 1980s) parts of the analysed period. The response of the second group, which consist of lower sites (sites 4-6; 706 – 717 m a.s.l.) was different. For these sites the correlation values were at the similar, low and insignificant level till second part of 1980s (except the site 4, for which the correlation values start to rise in 1970s; Figure 1.). The situation changed in the second part of 1980s when the unification of reaction of two groups was observed, with very sharp rise in correlation values. Since the late 1990s the correlation coefficients for all sites has become significant. In the last years of the analysis the correlations seem to stabilize for prevailing number of sites (Figure 1).

The response of trees to temperatures of August of the year preceding the tree ring formation is consistent among sites in whole analysed period (Figure 2). The values of correlation differ for particular site chronologies, but the general trend of lowering of values of correlation is observed in all of them. Since the middle 1980s the sharp trend drop can be observed. The negative correlation values reach the significance level for 4 among 6 analysed sites in the next decade (Figure 2). After, again very dynamically, the negative correlation decrease and only for one site stay significant till the end of the analysis period.

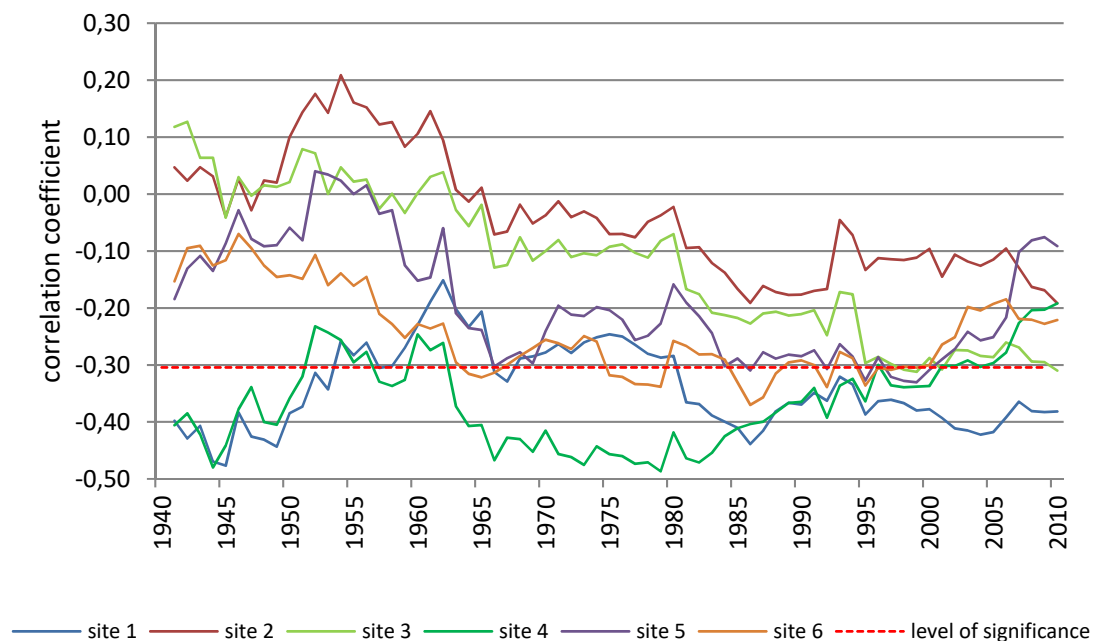
The response of trees from particular sites to previous July temperatures is the most diverse among the analysed results. In general, in 1960s the process of strengthening negative association between tree-ring growth and temperature has started, with some of the sites reaching the level of statistical significance almost instantly or in the next decades (Figure 3). It can be also noticed that the highest negative response characterised sites with southern aspect component and site located near the top of the mountain.



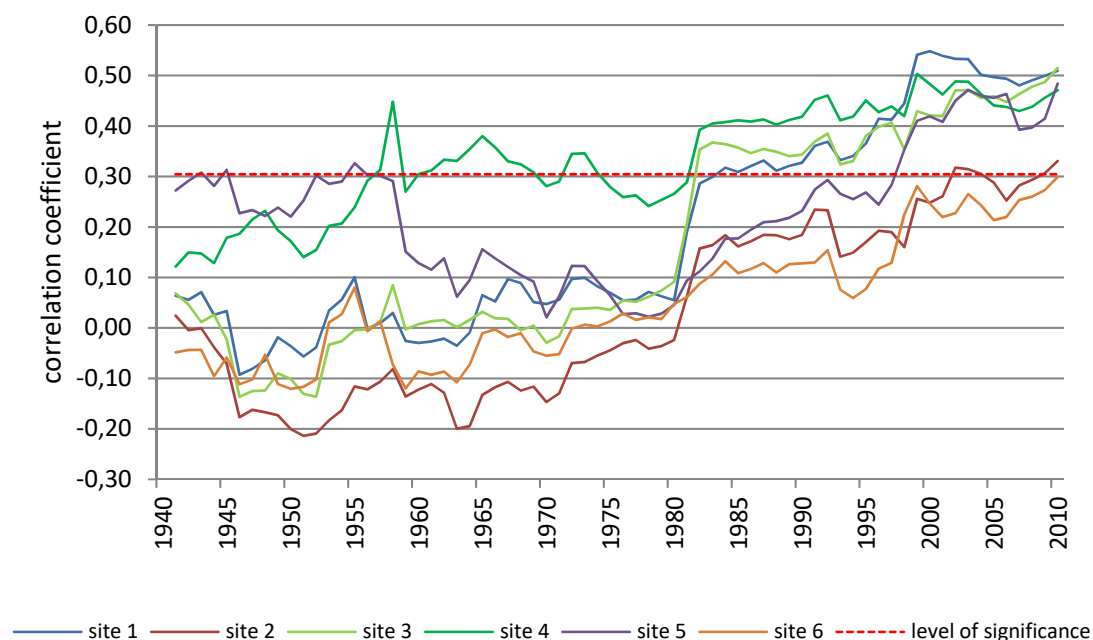
**Figure 1.** Results of moving correlation analysis between six site tree-ring width chronologies and average May temperature. Pearson correlation coefficients were calculated for 40-year intervals, for the period 1901–2010.



**Figure 2.** Results of moving correlation analysis between six site tree-ring width chronologies and average August temperature of the previous year. Pearson correlation coefficients were calculated for 40-year intervals, for the period 1902–2010.



**Figure 3.** Results of moving correlation analysis between six site tree-ring width chronologies and average July temperature of the previous year. Pearson correlation coefficients were calculated for 40-year intervals, for the period 1902–2010.



**Figure 4.** Results of moving correlation analysis between six site tree-ring width chronologies and total July precipitation of the previous year. Pearson correlation coefficients were calculated for 40-year intervals, for the period 1902–2010.

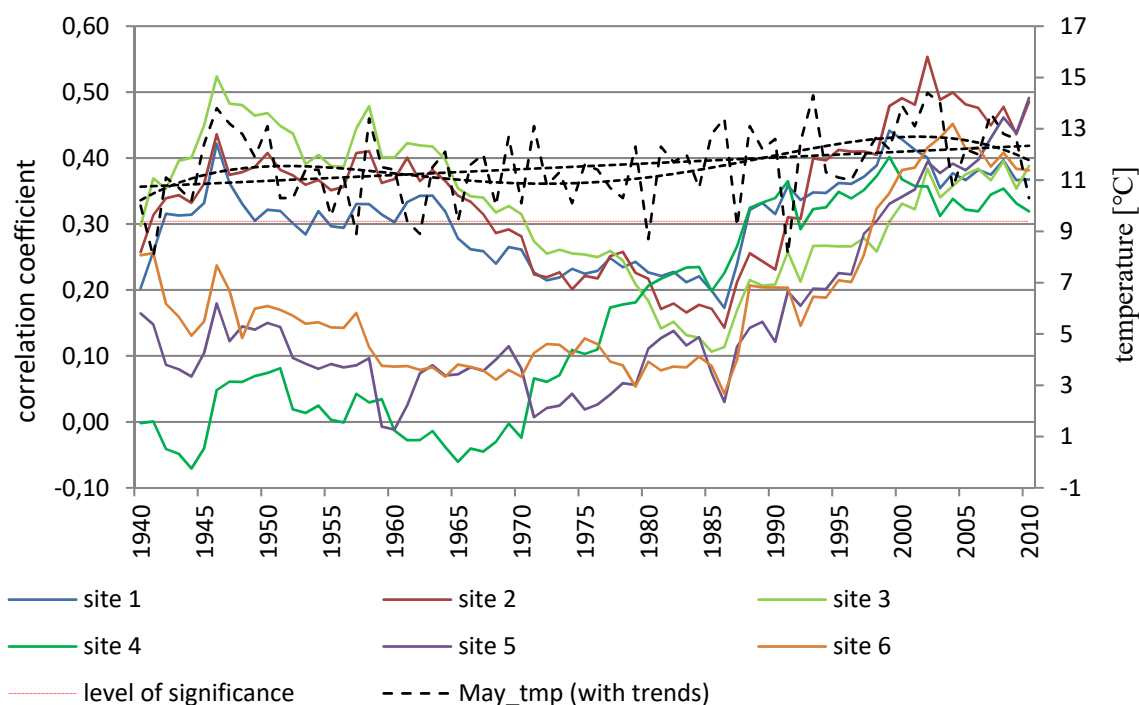
In the results obtained for the last analysed variable (previous July precipitation) two periods with different trees reaction can be distinguished. In the first one (till the end of 1970s), a lot of discrepancies in reaction between sites can be seen (Figure 4). Then, from the beginning of 1980s the sharp unification in response can be observed, which became positive for all sites, with the growing number of significant values of correlation over time.

#### 4. Discussion.

The positive trend in temperature in Poland was demonstrated by many authors, whose analysed instrumental data records since 1951 (e.g. [8-10]). The rise in average yearly, spring and summer temperatures was observed [10]. Among the months, for which the upward trend is the most distinct, May [8-10], August [9-10] and July [10] are mentioned. What is more, Degirmendžić et al. [8] points out rapid pace in warming for the last 25 years of the XX century. The increase in temperatures since 1980s was also indicated by Michalska [9]. Rising of average yearly, spring and summer temperatures is also expressed by rising of positive temperature anomalies since the end of 1980s [10]. All factors describe above coincide with observed trends and the rapid change in correlation results trends observed for May and August in the middle 1980s. However, the association between the tree-ring growth and temperature was opposite for mentioned months: positive for May and negative for August. Higher temperatures at the beginning of growing seems positively influence the tree-ring growth of larch, but too high temperatures in previous summer, that can have negative effect on bud formation, indirectly negatively influence the tree-ring growth in the next year (please see [6] for more details).

Similarly, as for August, the correlation with previous July temperatures is mainly negative; this trend is visible in all sites since 1960s. Some deepening of the trend can be observed also at the beginning of 1980s, but the response of trees is not as consistent as for two above mentioned factors. For the same month (previous July), the sharp rise of correlation between tree-ring growth and precipitation, since the beginning of 1980s, can be observed (Figure 4). Similarly, to the results obtained for May temperatures, the reaction of trees became also more consistent since then (Figure 4). The summer precipitation totals seem rather stable in the last 60 years [11] in contrary to rising of July temperature [10]. It suggests that the rising of correlation observed for precipitation is can be indirectly caused by rising temperature in the last decades (temperature rise increase evapotranspiration rates and water stress, compare [12]).

The differences in results for particular sites suggest its relevance to sites location. It can be seen in the results for May temperatures in the first part of the analysed period (Figure 1). However, as it was mentioned before, the general rising trend in May temperatures is observed, some deviations from this trend can be seen (Figure 5). In the first part of the 1940s and from the late 1950s to the end of 1970s the reduction of average temperature values can be observed. Referring it to the decreasing of correlation values for May in the period from early 1970s till the middle of 1980s, recorded for the first of distinguished group of chronologies (i.e. sites 1 – 3; Figure 1 and 5) it can suggest the existence of some temperature threshold below which the trees do not respond to temperature in May. The different response observed for the second group of sites can suggest that the sites can differ in the threshold: the temperatures which were sufficient to cause a positive effect (that were above the hypothetical trigger point) on trees from the sites of the first group did not start a significant reaction in trees from the second group. The differences in hypothetical threshold can be a result of altitude because the first group consist of higher sites whereas the second one represents the lower sites. However, the differences in altitudes between two mentioned groups of sites are rather small (about 50 meters of difference between the lowest and highest site) and more studies are needed to confirm this. The observed consistence in response of all sites since the middle of 1980s suggests that the mentioned temperature threshold was exceeded for all sites in the last years. The argument for that is mentioned above a significant rising in May temperatures in the last decades.



**Figure 5.** Results for May and average monthly temperature (gridded data) with observed trends (dotted lines).

The observed differences in responses of particular sites to the same climatic factors suggest its relevance to site-related factors. The example can be site 4. The response of this site to temperature in May, however more similar to the other sites of the second distinguished group, shows some differences: the positive trend observed in correlation values started here earlier (Figure 1). This site exhibits also differences in the response to previous July climatic conditions. The positive correlation with precipitation and negative with temperature was the most distinct and strong among all sites. Differences in reaction in comparison with other sites can be a result of specific location of site 4: near the top of the exposed mountain summit. The high insolation and windy conditions of this site are probably responsible for observed reactions. The positive effect of rising May temperature affected the trees growing here earlier than in other sites of the second group (sites 5 and 6). Specific location could also make larches more sensitive to the dry conditions in July. Some similarities in response to July temperatures can be seen in two other sites (site 1 and 6), which are located at slopes with southern aspect (Figure 3 and 4). It can suggest, that the strongest impact of July temperatures on tree-ring growth concerns sites more exposed to sun.

## 5. Conclusions

The variations in tree-ring growth response of larch to climatic factors over the analysed time period were observed. The variability of climate-growth relationship was observed for all sites. The growing positive association of tree-ring growth with May temperatures and previous July precipitation, and negative with previous August temperatures were recorded. A rapid change in correlation rate in 1980s was found for above mentioned factors. The observed trends in correlations can be related to rising temperatures in the last decades. The differences between analysed sites in their response to particular climatic factors (in both: the dynamic and the magnitude) can be a result of their specific location.

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