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# TRACE
## Tree Rings in Archaeology, Climatology and Ecology
## Volume 8

## Proceedings of the DENDROSYMPOSIUM 2009
April 16th – 19th, 2009 in
Otočec, Slovenia

Edited by:
Tom Levanič, Jožica Gričar,
Polona Hafner, Robert Krajnc, Špela Jagodic,
Holger Gärtner, Ingo Heinrich
and Gerd Helle

Scientific Technical Report STR10/05

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# Preface

This volume contains 23 short papers which summarise the main subjects of talks and posters presented at the eighth TRACE (Tree Rings in Archaeology, Climatology and Ecology) conference organized by Jožica, Gričar, Tom Levanič, Špela Jagodic, Robert Krajnc and Polona Hafner and held in Otočec, Slovenia on April 16th – 19th, 2009. The annual TRACE conference supports networking and scientific exchange between scientists and students involved in the study of tree rings from different regions of Europe and from other continents. This annual dendromeeting is an initiative of the 'Association for Tree-Ring Research' (ATR). A high scientific level was maintained at the conference as at previous TRACE conferences, but an informal forum was simultaneously provided for young scientists and students to discuss concepts and ongoing or completed projects.

The conference was organised by the Slovenian Forestry Institute and financially supported by Slovene Research Agency. There were 79 participants at the conference from Belgium, Bulgaria, Canada, Croatia, Czech Republic, Finland, France, Germany, Italy, Ireland, Netherlands, Poland, Portugal, Romania, Slovenia, Spain, Sweden, Switzerland and United Kingdom. The oral and poster presentations were given by participants representing a wide spectrum of tree-ring research. In total, 43 talks presenting different fields of tree-ring science were grouped into four main sessions – dendroecology, dendroclimatology & dendrogeomorphology, archaeology and wood anatomy and cambium dynamics. During the conference 37 posters covering these fields of study were put on display for the audience.

Three talks were given by invited speakers.
Dr. Neil Loader from the School of the Environment and Society (Swansea University, United Kingdom) presented recent strengths, weaknesses, limitations and potential of stable isotopes in tree rings. Dr. Jacques Tardif from the Canada Research Chair in Dendrochronology (University of Winnipeg, Canada) talks how anomalies in tree-rings can be used as indicators of climate and climate change. Dr. Holger Gärtner from the department of dendro sciences (WSL, Switzerland) presented new tools in wood anatomy for time series analysis.

In this volume of the TRACE Proceedings 2009 you will find 23 short papers on different aspects of tree-ring studies. We would like to thank the reviewers for their valuable comments on the first versions of these manuscripts. The organisers of the conference also wishes to thank sponsors of the TRACE 2009 conference - UMS München, Germany and Regent Instruments Inc., Canada, whose contribution helped support the conference. Appreciation is also given to all participants for their valuable work, discussions, and exchange of ideas.

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Jožica Gričar
Špela Jagodic
Robert Krajnc
Polona Hafner
Holger Gärtner
Ingo Heinrich
Gerhard Helle

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TRACE 2009 Conference, April 16th – 19th, 2009, Otočec, Slovenia

Organized by:

Slovenian Forestry Institute, University of Ljubljana, Slovenia

# SECTION 1

# ECOLOGY & GEOMORPHOLOGY

# Dendroclimatological investigation on radial growth of silver fir from inside and outside distribution range in Poland

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## Introduction

Trees growing in temperate climate zone form new layers of wood year by year. Size of the annual diameter increment depends on many factors, among which age, tree's condition and meteorological factors (mainly the temperature and precipitation) are the most important (Fritts 1976). Spatial distribution of tree species is a result of arrangement to climate factors connected with geographical localization and elevation. These factors limit possibility of the tree growth in different regions of the world. Growth of trees that occur out of their natural distribution range is limited mainly by arrangement to meteorological factors. So we can expect their tree-ring sequences to be different than in case of individuals growing in optimal conditions.

Silver fir (*Abies alba* Mill.) covers less than 2% of the whole afforested area in Poland, but is one of the most important species in mountains and uplands (Jaworski 1995). In the second half of the previous century, fir suffered serious decline (so-called 'Tannensterben') caused mainly by industrial emissions (Eckstein et al. 1983, Jaworski et al. 1988, Becker & Levy 1989, Krause 1989, Visser 1989, Dobrowolska 1998, Elling 2001, Elling et al. 2009). However, in recent decades a recovery of growth can be observed (Podlaski 2000, Zawada 2001, Elling et al. 2009). Transformation of Polish economy resulted in decrease in number of major pollutants and in implementation of new technologies. This reduced emissions and, as a result, stopped the decline phenomenon (Filipiak & Ufnalski 2004). Moreover, current reconstruction of silver fir stands that aims at the species structure consistent with the habitat type results also in slight, but consecutive, improvement of silver fir condition in Polish forests. In Poland, silver fir has northernmost limit of its natural range (Fig. 1). Beyond this border it appears only in solitaire spots. Some of these sites are considered to be of natural origin (e.g. Białowieża Primeval Forest – Boratyński 1983). However, most of fir stands in western and northern Poland were planted in order to examine the possibility of increase in forest productivity and biodiversity by introduction of new species for the given region.

The main purpose of this study was to compare tree-rings sequences of silver fir growing inside and outside the distribution range and investigate their response to climate conditions.

## Material and methods

### *Study sites*

Study sites located inside and outside the natural distribution range of silver fir were selected to investigate differences in increment reaction of this species (Fig. 1). Sites representing fir growing outside area of its natural abundance were located in central and eastern part of the Pomorskie Lakeland, in Kartuzy, Osusznica and Sławno forest districts. Sampling plots were located in stands where silver fir constituted 10-70% of the species structure. In Kartuzy and Sławno trees grew mostly in fresh mixed broad-leaved forest habitat conditions. Cambisols, very often of poor quality, are the dominant soil type. In turn, fresh forest habitat type was prevailing in Osusznica. Zagnańsk site was chosen as an example of firs living in the optimal conditions of the natural distribution range. Average share of fir in species structure in that site equaled 36%. Sampled trees grew mostly in upland forest habitat conditions on peat-glial soils.

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*Figure 1: Silver fir natural distribution range in Poland (grey area) and sample plots localization (A – Sławno, B – Osusznica, C – Kartuzy, D – Zagnańsk).*

### *Field sampling and measurements*

Sampling plots were located in the stands, where silver fir dominated or had an important share in species structure, and generally was growing in good, appropriate for that species habitat conditions. Sampling took place in summer 2005 (Zagnańsk) and in summer 2007 (stands outside the distribution range). Dominant and healthy trees were sampled, and one increment core per tree was extracted from the circumference at the breast height. Altogether 421 increment cores were taken. In the laboratory cores were air-dried and sanded with increasingly finer sanding papers. CooRecorder image analyzing program (www.cybis.se) was used to measure annual diameter increments to the nearest of 0.001 mm.

### *Chronology development*

Individual series were cross-dated visually with the CDendro (www.cybis.se) software as well as statistically using Gleichlaeufigkeit coefficient (Eckstein, Bauch 1969) and t-value (Baillie, Pilcher 1973). The dated tree ring series were statistically checked using COFECHA program (Holmes 1999, Grissino-Mayer 2001). Series that showed dissimilarity were excluded from the further analysis as they might limit the common signal in the chronology. Altogether 379 tree-ring series were used to build the chronologies. Chronologies were constructed according to the procedures described by Fritts (1976), and Cook and Kairiukstis (1990). To pronounce climate-related high-frequency signal and to minimize long-term age-dependent trend, the standardization was done for each tree ring width series in the two-staged detrending using negative exponential curve and the linear regression function. In the next step the indices were prewhitened using an autoregressive model selected following the minimum of AIC and averaged across all series using bi-weight robust estimation of the mean (Cook 1985). Standard and residual chronologies were computed for Zagnańsk, Kartuzy, Osusznica and Sławno sites with CRONOL software (Holmes 1999).

### *Dendroclimatological analyses*

Dendroclimatological analyses were performed basing on meteorological data from the Climate Research Unit and Tyndall Centre resources (www.cru.uea.ac.uk) that covers period 1901-2002 (Mitchell, Jones 2005). High resolution (0.5°) grid data set (CRUTS 2.1) provided mean monthly air temperature and precipitation.

We use simple correlation analysis to study relationship between annual ring width and temperature and precipitation. Each residual chronology was correlated with historical climate data consisting of series of average monthly air temperature and sum of precipitation. The significance of Pearson's correlation coefficients was checked at 0.05 significance level. As the conditions in the period prior to the ring formation affect this process in a great measure (Fritts 1976) the analysis included thermal and pluvial conditions spanning from July of the previous growth year to September of the current growth year. DendroClim2002 (Biondi, Waikul 2004) software was used to calculate bootstrapped correlation coefficients.

Pointer year analysis was used to detect the influence of climate on extreme growth fluctuations. Such study informs us about tree's response to unusually favorable or unfavorable conditions when exceptionally wide or narrow tree rings are formed (Schweingruber et al. 1990). A given year was considered as a pointer year (negative or positive) when the same response was observed on at least 80% of not less than 10 trees on each sample plot. According to some recommendations (e.g. Schweingruber et al. 1990) the computation of pointer years were performed on raw tree ring data with WEISER program (Gonzales 2001).

## Results

### *Chronologies*

Chronologies covering the period of 1870-2006 were built for four study sites representing silver fir growing inside and outside the natural distribution range. There were no missing rings found in analyzed tree-ring series. Mean tree-ring widths on sites from outside the distribution range were very variable spanning from 2,43 to 3,57 mm. Average increment in Zagnańsk site was, in general, smaller and less variable equaling from 2,27 mm (Fig. 2). All sites present decrease in mean tree-ring width starting in 1970s. This is evidence of fir decline observed all over Europe in that period. In last decades (since ca. 1990) significant improvement in growth rate can be noticed, as analyzed trees produced wider rings.

No clear pattern in mean sensitivity and autocorrelation of standard and residual chronologies can be observed (Tab. 1). The lowest values characterize Sławno site located near the Baltic Sea.

### *Response to climate*

Relationships between tree-ring width indices and mean monthly temperature and sum of precipitation were calculated for the period of 1901-2002. Silver firs from inside and outside the specie's natural distribution range show different response to thermal conditions (Fig. 3). Sites from northern Poland exhibit positive influence of temperature in winter, early spring and summer of the year when the tree ring is formed. Thermal conditions of summer of the year prior to the ring formation cause negative increment reaction (especially Kartuzy site). Significant correlation was found for all sites from outside the distribution range for period January-March and July-August. In turn, trees from inside the range show significant negative reaction to thermal conditions in March and July-September. Reaction to pluvial conditions is more diverse (Fig. 4). All analyzed sites exhibited negative response to precipitation in January. In turn, positive relationship with water supply can be observed in February. Similarly, the same pattern represents July. Additionally, firs growing inside the distribution range in Zagnańsk site show significant negative relationship with precipitation in August of the year prior to the ring formation and in May of the current year.

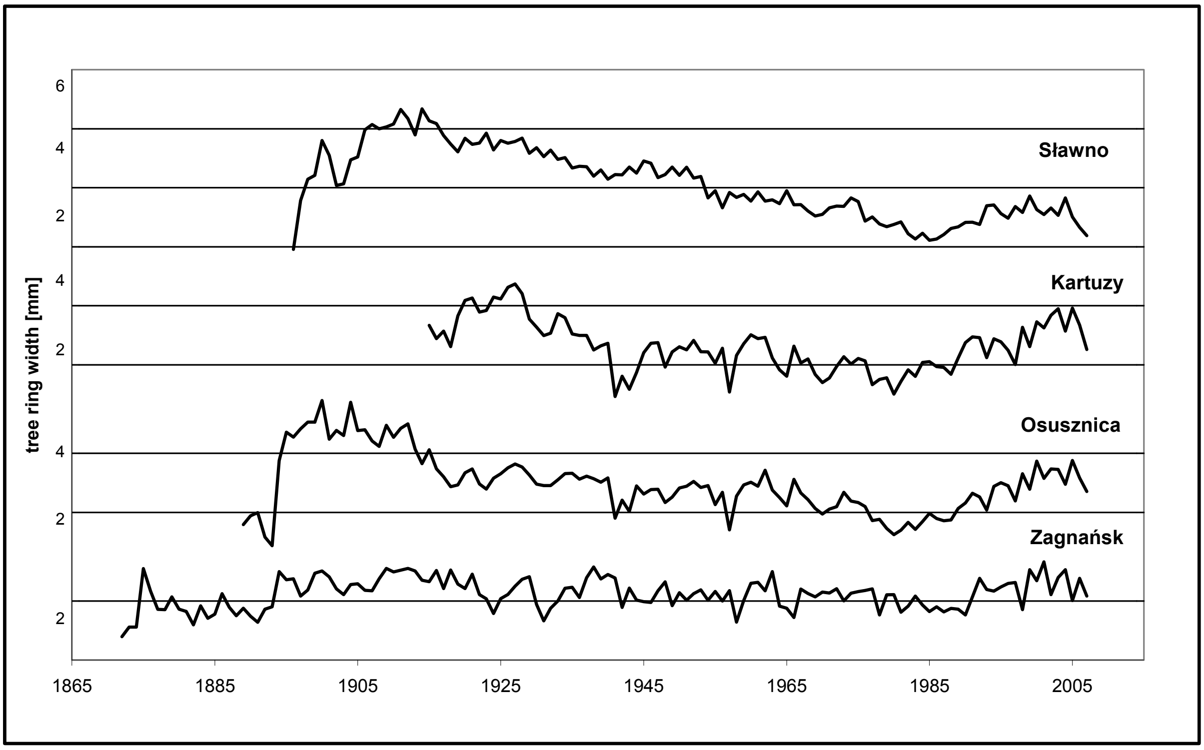

*Figure 2: Mean tree ring widths at individual study sites.*

*Table 1: Basic characteristics of silver fir chronologies.*

| Study site | Period | Years | Index standard deviation | Mean sensitivity | Autocorrelation |
|---|---|---|---|---|---|
| standard chronologies | | | | | |
| Zagnańsk | 1870 - 2005 | 135 | 0.233 | 0.171 | -0.08 |
| Kartuzy | 1914 - 2006 | 92 | 0.844 | 0.189 | 0.77 |
| Osusznica | 1878 - 2006 | 128 | 0.249 | 0.164 | 0.63 |
| Sławno | 1900 - 2006 | 106 | 0.187 | 0.139 | 0.55 |
| residual chronologies | | | | | |
| Zagnańsk | 1872 - 2005 | 133 | 0.191 | 0,222 | -0,05 |
| Kartuzy | 1915 - 2006 | 91 | 0.206 | 0.236 | -0,12 |
| Osusznica | 1879 - 2006 | 127 | 0.172 | 0.187 | -0.10 |
| Sławno | 1900 - 2006 | 106 | 0.130 | 0.164 | -0.22 |

*Pointer years*

Only 1956 and 1964 were identified as a common negative pointer years for sites inside and outside the natural distribution range of silver fir (Tab. 2). Very narrow ring was formed by almost all trees in Zagnańsk, Osusznica and Kartuzy. Some individuals from the Świętokrzyskie Mountains and Kaszubskie Lakeland had common negative pointer years also in 1940 and 1979. No pointer years were found for silver firs growing in Sławno site.

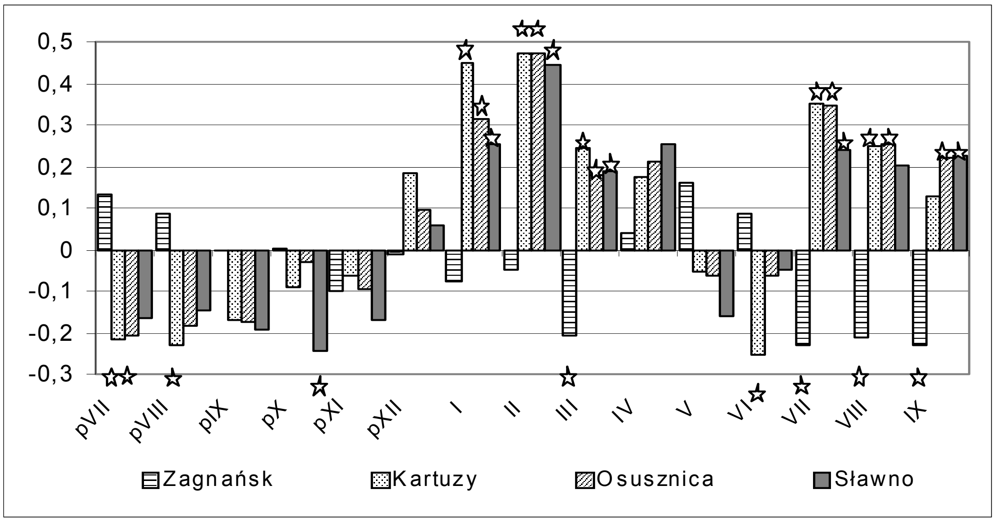

*Figure 3: Coefficient of correlation between tree-ring width and mean monthly temperature (stars indicate values significant at 0.05 level).*

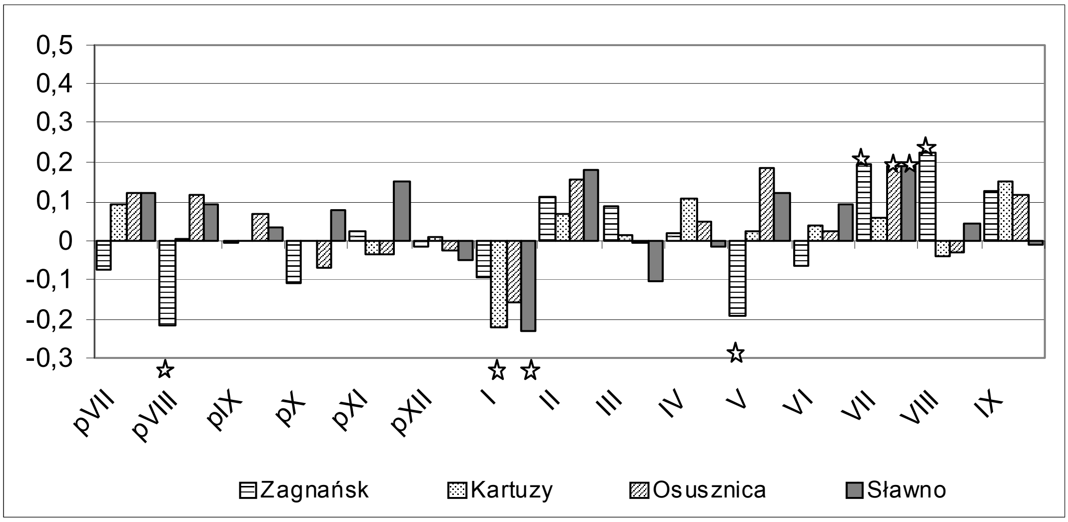

*Figure 4: Coefficient of correlation between tree-ring width and mean monthly precipitation (stars indicate values significant at 0.05 level).*

*Table 2: Pointer years of silver fir in Poland.*

| Pointer year | Zagnańsk | Kartuzy | Osusznica | Sławno |
|---|---|---|---|---|
| positive | 1873, 1961 | 1959, 1965 | 1965 | — |
| negative | 1870, 1876, 1889, 1922, 1929, 1940, 1956, 1964, 1976, 1996 | 1940, 1942, 1947, 1956, 1964, 1969, 1979, 1996, 2006 | 1956, 1964 | — |

## Discussion

Presented mean annual diameter increments of silver fir from sites localized outside the distribution range are similar to those obtained for trees growing in Olsztyńskie Lakeland (2,84 mm; Koprowski, Gławenda 2007). In turn, average tree-ring width from Zagnańsk site is similar to or merely higher than values reported for stands growing inside the range in the Beskid Sądecki Mountains and Ciężkowice region (Szychowska-Krąpiec 1999) as well as in the Karpaty and

Sudety mountains (Feliksik 1993). Analyzed firs both inside and outside the range recovered from the decline of the 1970s, which is indicated by the increasing growth trend in last 20 years (Fig. 2). Analogous pattern was also observed in other sites in Poland (Podlaski 2000, Koprowski, Gławenda 2007) and for Bavaria (Wilson & Elling 2004, Elling et al. 2009). Interestingly, no missing rings were found in analyzed series. This stands in the contrary to the frequent observations of that phenomenon reported by Elling et al. (2009).

Results about the influence of thermal conditions on radial growth of silver fir in Poland are similar to those presented in literature as far as sites from outside the distribution rage are concerned. Feliksik (1990) and Feliksik et al. (2000) reported the important role of winter temperature in the process of tree-ring formation of firs growing inside the distribution range. Koprowski and Gławenda (2007) found similar relationship for firs in the Olsztyńskie Lakeland, i.e. outside the natural distribution range. Interestingly, firs growing within the distribution range (Zagnańsk site) show pattern of the response to temperature that is opposite to observations published by Feliksik (1990).

Although many papers report that silver firs are drought dependant (Eckstein et al. 1983, Feliksik 1990, Desplanque et al. 1999), presented results, in general, do not show any significant response of analyzed firs on water deficit. Koprowski and Gławenda (2007) observed similar relationship for firs from the Olsztyńskie Lakeland and explained this fact with enough amount of moisture in the habitat and optimal distribution of water delivery during the year. Only in July trees from Zagnańsk, Sławno and Osusznica showed significant correlation between tree-ring width and amount of precipitation (Fig. 4), which confirms results obtained by Feliksik (1990). The most interesting is fact that all sites characterize with negative response to precipitation in January. This may indicate that moisture surplus in that time is unfavorable for firs. Wilson and Elling (2004) also report poor correlation between tree ring widths and precipitation (March –August) for firs in Bavaria.

Pointer year analysis proved that response of firs to the extreme environmental condition depends in great measure on the localization. The more inland site was located, the more sensitive it was. Lack of pointer years in Sławno site might be caused by the neighborhood of the Baltic Sea. Moreover, poor representation of commonly recognized negative pointer years (1940, 1976, 1979 and 2003) may suggest that there are other (perhaps not natural) factors that might have softened the harsh climate conditions.

## Conclusions

Studied stands of silver fir growing inside and outside the species natural distribution range recovered from the growth decline of the 1970s exhibiting constant increase in diameter increment over last 20 years. Dendroclimatological investigation showed differences in the response of trees from various sites to thermal conditions, while the relationship with pluvial conditions was in great measure similar independently on the localization. Analyzed trees from outside the distribution range seem to prefer warm and dry winters and warm middle part of the growing season. In turn, mild and rather wet summer seems to be the most favorable for firs growing within the distribution range.

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# Tree-ring record of slope processes and gully floor dynamics, Strzelińskie Hills, Sudetes Mountains

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## Introduction

Loess is a common deposit in the Southern part of Poland. Polish loess layers are situated in the central part of the European loess belt. Loesses in SW Poland occur in several isolated patches which differ in sediment thickness, stratigraphy and physical properties (Jary et al. 2002).

The changes in land use, development of agriculture and ongoing deforestation lead to severe soil erosion and creation of gullies, which are the most characteristic features of the loess areas (Fig. 1).

Gully initiation and evolution usually result from a combination of natural and anthropogenic causes. The main factors influencing gully erosion are the quantity and intensity of precipitation and climatic fluctuations (Burkard & Kostaschuk 1995). The intensity of the interaction of these factors depends directly on the land relief. Local hillslopes and drainage basin areas are the most important topographic parameters affecting gully erosion (Vandekerckhove et al. 1998). Other significant factors are lithological conditions, the thickness of aeolian deposits, as well as the underlying rock structure (Beavis 2000, Kirkby & Bull 2000, Oostwoud Wijdenes 2000).

The density of the gully network varies from 10 km/km$^2$ in the SE Poland to 0.15 km/km$^2$ in the SW Poland. The gullies, which are analyzed in this study, are located in forested areas in the Sudetes Forefield (SW Poland). Little is known about their spatial distribution, as well as about their morphological and topographical characteristics, mainly because most studies focus on ephemeral gully development under cropland. Even though most gullies in SW Poland are currently located under forest, rill and ephemeral gully erosion is observed on their slopes and bottoms (Fig. 2).

*Figure 1: A typical forested loess gully in the SW Poland*

*Figure 2: Erosion on the slope of the road gully, SW Poland*

The aim of the study is to determine the modern geomorphic processes in the forested gully systems on the basis of dendrochronological research.

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## Study area

The research area is located in the south-western Poland in the Strzelinskie Hills (250-390 m a.s.l.) (Fig. 3). This part of the Sudetes Mountains is built of Proterozoic metamorphic and crystalline rocks covered by loess and slope deposits.

The area is characterized by a temperate warm climate with a mean annual rainfall ranging from 600 to 700 mm (Sobik 2005). Rainfall distribution is irregular with high-intensity rainstorms in spring and summer (i.e. 1-3 mm/min over short periods), what intensifies the erosive potential of the single events (Raczkowski 1958, Dziarski 1968, Mastalerz 1986, Górecki & Klementowski 1989).

Soils in the investigated areas are degraded by overland and concentrated linear flow. This is due to short but intensive storms falling on a dry soil surface. Rill and ephemeral gully erosion plays a significant role in soil degradation in the loess areas of SW Poland (Jary & Kida 2002).

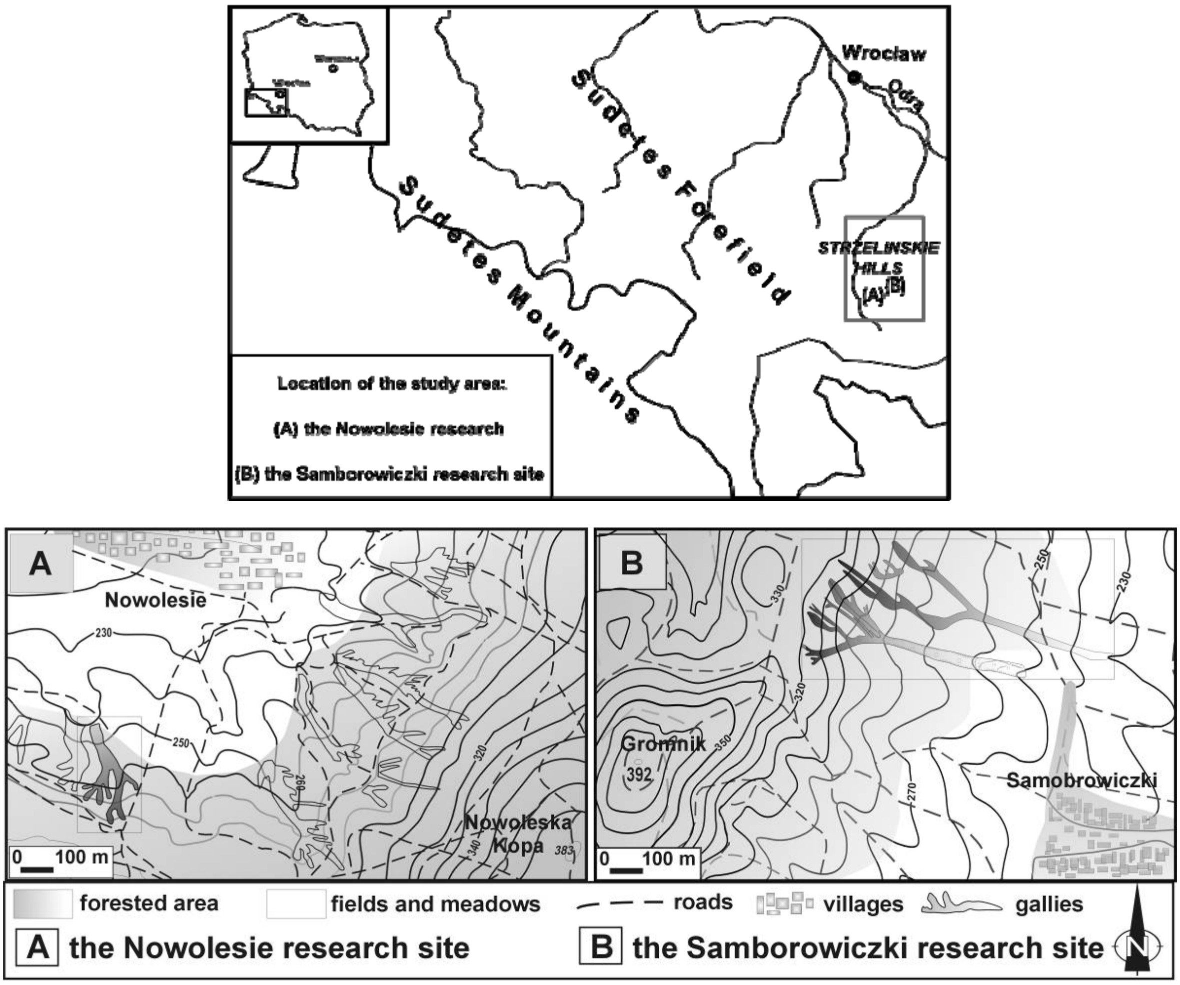

Figure 3: Location of the study areas: (A) the Nowolesie research area, (B) the Samborowiczki research site.

Natural vegetation of the Strzelinskie Hills consists of fertile Sudetian beech wood (*Dentario enneaphylli-Fagetum*) but currently, as a result of anthropogenic degradation, beech trees (*Fagus sylvatica*) grow mainly in the upper parts of the massif. The middle and lower parts of slopes are covered with mixed forest including spruces (*Picea abies*), pines (*Pinus silvestris*), maples (*Acer platanoides*), silver birches (*Betula pendula*) and sporadically oak (*Quercus robur*) and beech trees (Matuszkiewicz, 2001).

A dense network of gullies dissects eastern and western slopes of the Strzelinskie Hills. The research was carried out in three gully systems near Nowolesie village (Fig. 3A) and Samborowiczki village (Fig. 3B).

## Material and Methods

Three forested gullies were chosen for detailed research from the area of the Strzelinskie Hills. The research was based on an analysis of modern topographic maps (1:10 000 scale) and detailed field investigations. Cross-sections and longitudinal profiles were drawn using simple geodetic methods. Dendrochronological research consisted of the analyses of tree cores and exposed roots. Two cores at a height of about 1.2 m above ground level along an axis parallel to the slope gradient were collected from each tree. 56 cores from 30 maple trees (*Acer platanoides* L.) were examined (Fig. 4).

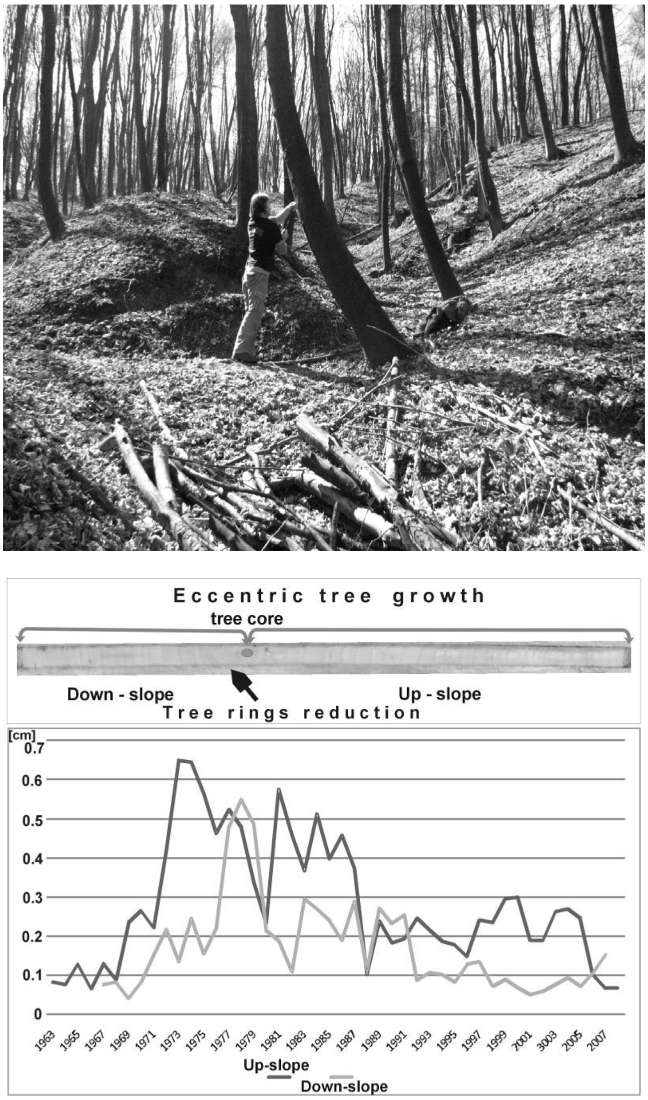

*Figure 4: Image of an increment core taken from an inclined maple tree showing eccentric growth due to the inclination. In the lower part tree-ring width variations in up-slope and down-slope sides of the analyzed maple tree.*

Exposed roots were analysed in the Samborowiczki gully system based on taking 10 cm- long parts of living exposed roots (Fig. 5). 21 samples were taken from 12 roots (11 trees: 5 pines, 3 oaks, 4 beeches). The samples were sectioned with a GSL-1 sledge microtome. Micro photos were taken for analysis of cell-size variations and other wood anatomy features.

*Figure 5: Example of exposed root on the slope of Samborowiczki gully system.*

The age of trees and exposed roots was measured by counting rings under a binocular microscope and using OSM 3.65 and PAST4 software. The size of cells in roots was measured using OSM 3.65 and ScopePhoto software. For the purpose of determining tree-ring reduction within cores collected from maples sampled on gully slopes, graphs were prepared presenting tree-ring width variation. Tree-ring width variation was matched to the chronology which had previously been prepared based on data from local maple trees. Distinct visible divergence between tree-ring widths in up-slope side and down-slope side of tree was interpreted as the increased activity of the slope and tilting of trees (Fig. 4).

## RESULTS

### *Morphology of the gullies*

The length of the gullies ranges from 0.3 to 1.0 km (Fig. 6, Fig. 7) and gully gradient varied from 0.07 to 0.16 m/m. The variability of the cross-sectional profiles are characteristic for gully systems. The upper parts of the gullies are V-shaped. The gradient of these sections reaches from 18º to 30º but the gully sides are gentle. The middle parts have flat bottoms and are 20-25 m wide. These are the deepest parts of the analysed gullies (6-9 m deep). The slopes are steep and their gradient reaches 40º. The lower sections of the gullies are 2-3 m deep and have flat bottoms too. Their gradient varies from 2º to 6º.

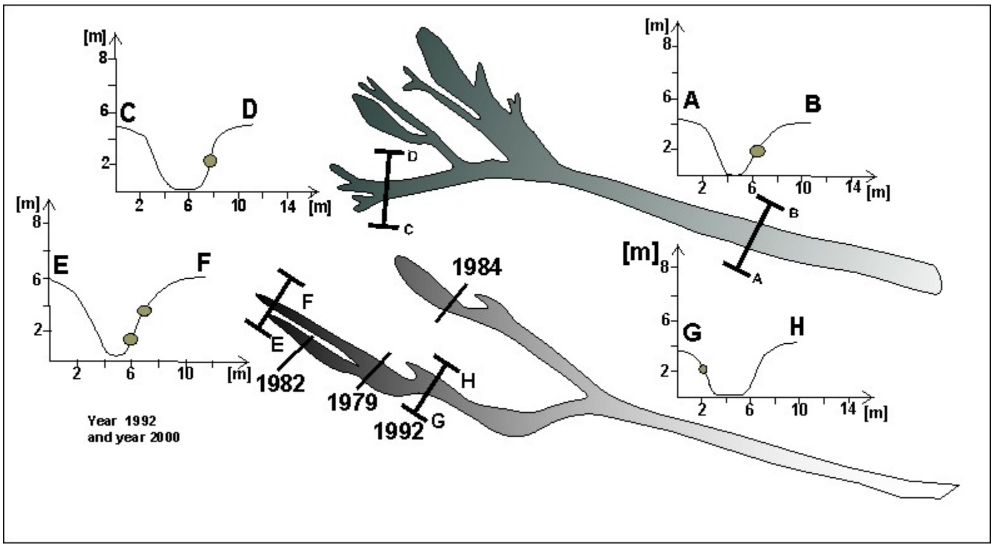

*Figure 6: Plan view with cross-sections of the gullies at the Samborowiczki research site. Dates indicate age of root exposure.*

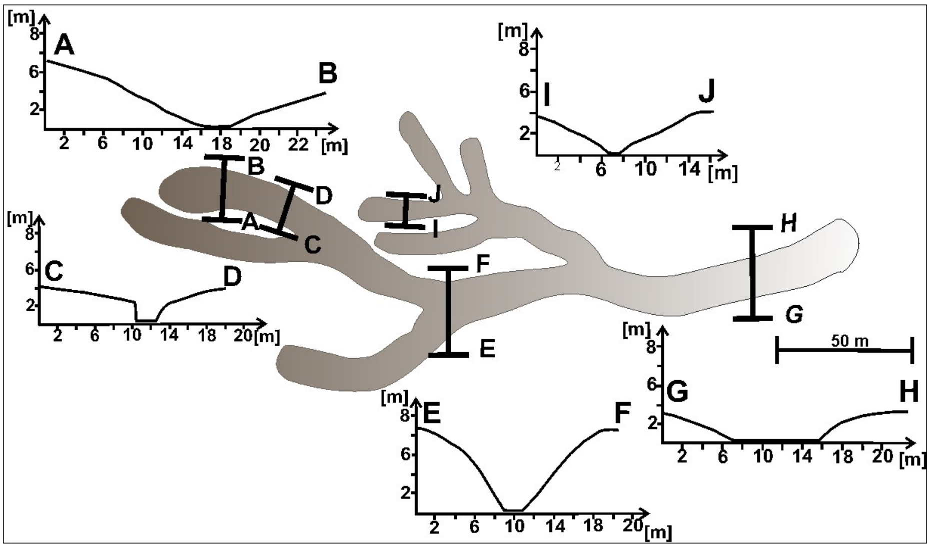

*Figure 7: Plan view with cross-sections of the gully at the Nowolesie research site.*

## Dating of wood

The research conducted by Gärtner et al. (2001) showed the possibility of determining an erosion episode based on anatomical changes occurring in root wood after exposure. It proved that cells/vessels within tree rings become more numerous and smaller after exposure (Fig. 8).The reduction of the size of earlywood cells in conifers or vessels in broadleaved trees within the rings of roots allow the dating of erosion episodes (Gärtner et al. 2001, Hitz et al. 2006). Clear division into early wood and late wood within tree-rings originating after exposure can be seen, but this feature already occurs when roots are close to the surface.

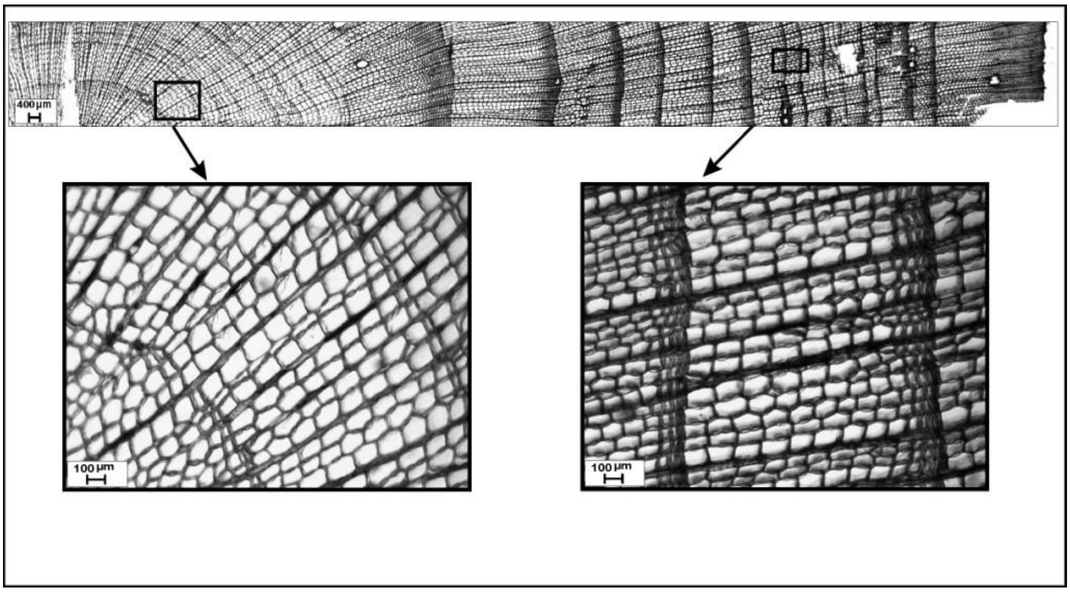

*Figure 8: Changes of the wood anatomy of a pine root cross-section following exposure in the Samborowiczki research site. Note visible reduction of the size of early wood cells after exposure: (A) Cells before root exposure (average size of cells - 160 µm), (B) annual ring after exposure (average size of earlywood cells – 106 µm).*

The age of roots and the time since the roots were exposed was analysed in the gully at the Samborowiczki research site (Fig. 6). Cell size measurements and observations of the other wood anatomical changes were used for dating of root exposure. The age of exposed roots indicates that this gully system was transformed several times during the last 50 years.

The vast majority of roots was exposed in 80’s and 90’s of the last century, to be more precise in 1982, 1984, 1992. The correlation of the dates gained from the samples of the roots indicates three significant episodes of erosion. The gully systems analysed are located in the area, where deciduous trees are dominating. These species develop diffuse-porous wood and are usually characterised by faint record of sequence of consecutive tree rings. Therefore examining the sequence of growth rings in deciduous trees has to pay special attention to a comparison that is to eliminate wedding rings, false rings or missing rings (Malik 2008). One of the crucial factors determining the reduction of tree rings is a mechanical stress that has an effect on trees. Eccentric tree growth is the effect of leaning of the tree that is the effect of increasing the activity of geomorphic slope processes.

The number of years with eccentric tree growth indicates the year of leaning of the tree and indirectly the year of an erosive episode. Tree-ring widths in cores collected from living maple trees were analyzed in the gully system in Nowolesie research site. Three parts were chosen for detailed research: upper and lower parts of the gully and the main left tributary (Fig. 7). Tilting of trees in the upper part was recorded in 1964, 1978, 1989 and 1994 (Fig. 9A), in the lower part in 1964, 1978, 1989, 1994 (Fig. 9B) and in the left tributary in 1973, 1974, 1978, 1986, 1994, 1997 (Fig. 9C).

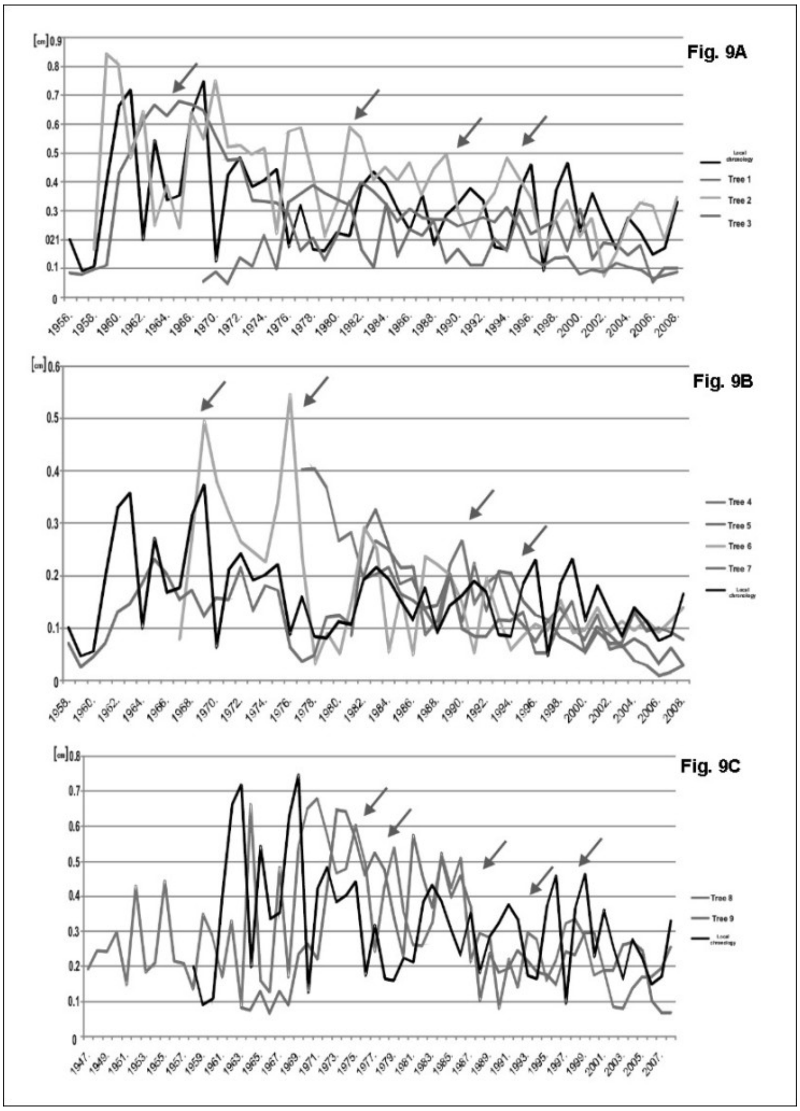

*Figure 9: Ring-width curves of selected trees (up-slope tree-ring width variations) from the gully sides from (A)the upper part, (B) the lower part and (C) from the main left tributary and local chronology.*

## Conclusions

First and foremost, the conducted research analyses proved that dendrochronology is a good tool to recognize the recent activity of the forested gully systems. Lack of synchronization of the exposure years of roots along longitudinal profile is connected with multi-phase development of the gully bottoms in local scale. Analysis of eccentric growth of trees brought similar results. The age of tilting of trees and increasing of slope movement activity is convergent along the longitudinal profile in the gully at the Nowolesie research site. Finally, trees and their annual-ring are an indicator of changes of intensity of geomorphic processes in gully-scale. The age of exposed roots informs about development of gullies in short sections.

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# Growth responses of *Abies alba* Mill. and *Picea abies* (L.) Karst at different altitudes in south-western Germany

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## Introduction

In Central Europe, the spring of 1976 and the summer of 2003 were characterised by extreme warm and dry conditions. In the Black Forest (south-western Germany), the growth reactions of silver fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* (L.) Karst) to these extremes were quite similar, as both species showed a negative growth reaction at low and high altitudes in 1976, and mainly at lower altitudes in 2003 (Kahle et al. 2008). However, in 1976 the degree of damage in silver fir was higher compared to that in Norway spruce, and in 2003 silver fir even seemed to increase its growth at higher altitudes.

The Regionalverband Südlicher Oberrhein (RSO) analysed the past and current climate in south-western Germany and made predictions about future climate changes. Since the 1930s, the average annual temperature for the region has increased with 0,9°C. Future climate scenarios foresee that the intensity and frequency of summer droughts is likely to increase and that the seasonality of precipitation will change (RSO 2006). It is important to understand how different tree species will react to these changing growing conditions. Tree rings provide insight into past environmental conditions, as intra-annual as well as year-to-year variations can often be attributed to changes in weather and climate conditions (Fritts 1976). Here we present results of a pilot-study on climate-growth relationships of silver fir and Norway spruce at different altitudes in the Black Forest.

## Material and Methods

The pilot-study has been performed along an altitudinal gradient in the southern Black Forest, south-western Germany (Fig. 1). Over the gradient, vegetation types gradually change from submontane beech-oak-fir forest, to montane beech-fir-forest mixed with pine, to high-montane fir-spruce forest (Schlenker & Müller 1978).

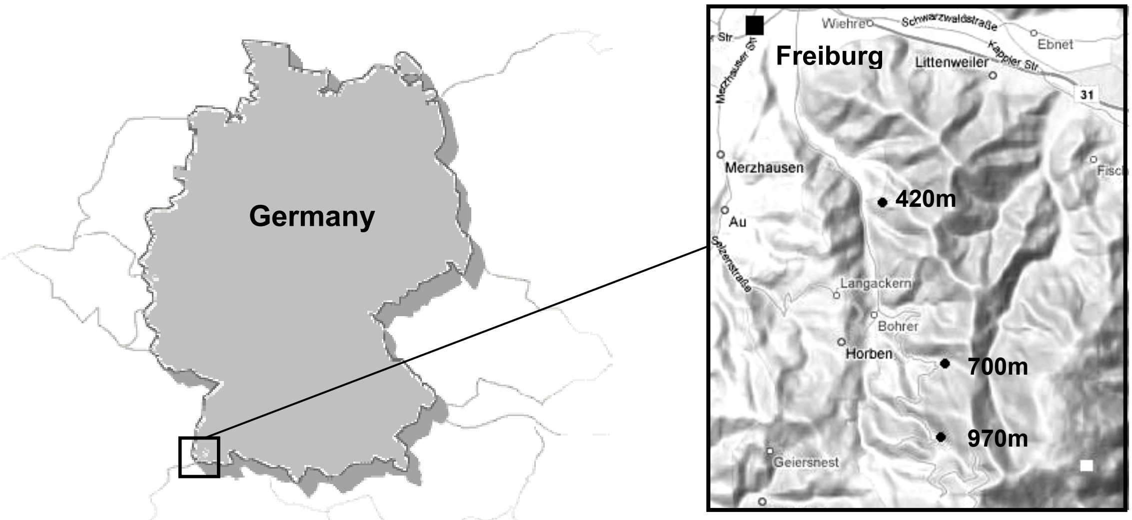

*Figure 1: Location map illustrating the dendrochronological sites.*

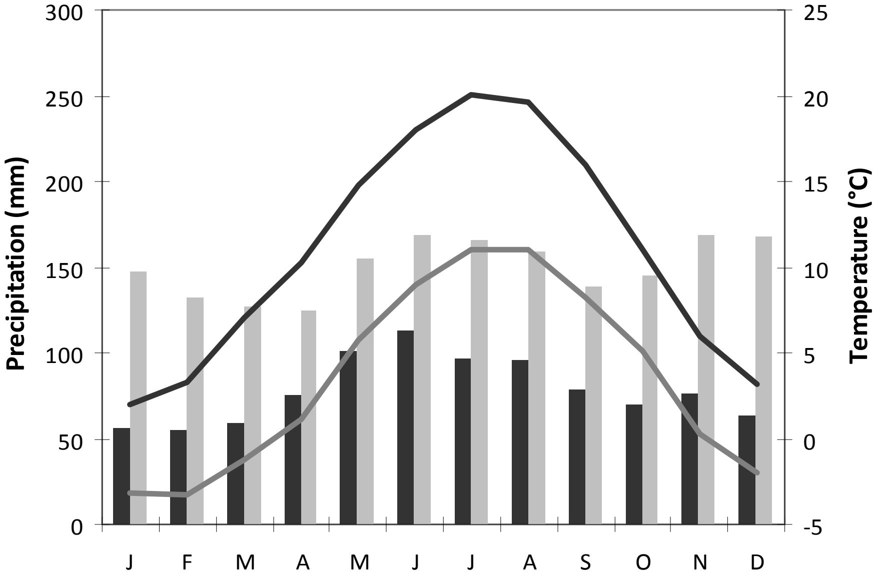

*Figure 2: Climate diagrams for the Feldberg (1490m a.s.l.)(grey) and Freiburg (236m a.s.l.)(black) for the period 1950-2003 showing monthly mean air temperature (lines) and monthly total precipitation (bars).*

The area has a maritime climate, characterized by balanced temperatures, high precipitation amounts, and a long and snow-rich but relative mild winter. Monthly temperature means vary with altitude (Fig. 2).

In total, 9 silver fir and 9 Norway spruce stem disks taken at breast height have been analysed. The disks were collected in the winter of 2004/2005 south of Freiburg at WSW-exposed sites at three different altitudes: 420, 700 and 970m a.s.l., that are referred here as low, medium and high elevation, respectively. The trees had predominant or dominant social status with no visual signs of damage.

The stem disks were air-dried and sanded in the Tree-Ring Laboratory of the Institute for Forest Growth. Annual radial growth rates were analysed in eight predefined directions using a semi-automated image analysis software developed by the institute. Tree-ring analyses were performed according to standard dendrochronological methods (Cook & Kairiukstis 1990).

Climate-growth relationships were calculated using single year analysis of the DENDROCLIM2002 program (Biondi & Waikul 2004). Annual radial growth was related with monthly mean temperature and total precipitation from the previous April to September of the current year. Climate data were provided by the German Weather Service.

## Results

Silver fir and Norway spruce showed different growth responses at different altitudes (Fig. 3). In 1976, annual radial growth of both species showed a depression at the high and medium altitude. At the low altitude, fir and spruce did not show a negative response in 1976, and were furthermore characterised by an unexpected growth-increase in 1977. In 2003, both species showed a strong growth decrease at low and medium altitudes. However, at the high altitude only the radial growth of Norway spruce was slightly affected by drought.

Climate-growth relationships for the period 1927-2003 were analysed for the high and medium altitudes only. The low-altitude chronologies were excluded since the growth reaction of these trees was clearly caused by another factor than climate (see discussion). A significant positive correlation was found between the growth of the high altitude fir and temperature in August, whereas spruce showed a positive correlation with temperature in May. The growth of both fir and spruce at the medium altitude show a significant negative correlation with temperature in July and

August of the previous year, and spruce shows a significant positive correlation with precipitation in June and July of the current year (results not shown).

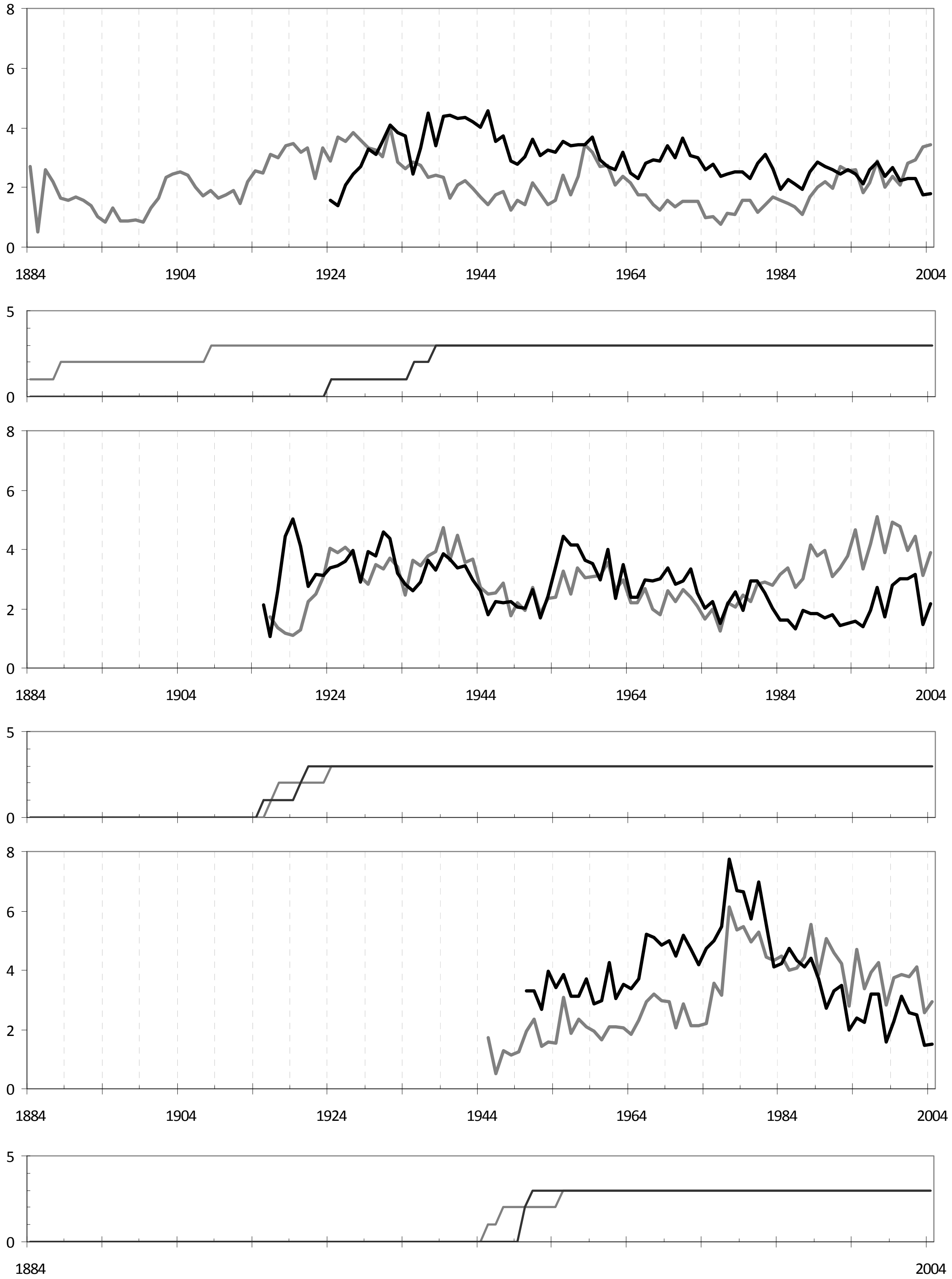

*Figure 3: Growth pattern (annual radial increment in mm) of silver fir and Norway spruce at 970, 700 and 420m a.s.l. and the number of samples through time.*

## Discussion

The silver fir and Norway spruce trees in the pilot study showed different growth responses at different altitudes (Fig. 3). Although growth depressions were generally found for both species in 1976 and 2003, silver fir did not respond noticeable at high altitudes in 2003. Altitude-related differences in growth responses can be explained by the observation that trees growing at high altitudes are temperature-limited, whereas trees at lower elevations are often precipitation-limited (Dittmar & Elling 1999, Kienast et al. 1987, Leal et al. 2007, Mäkinen et al. 2002b). The positive correlation 'altitude-precipitation' (Thomas et al. 2002) and the negative correlation 'altitude-temperature' are illustrated by studies from Switzerland and the Italian Alps, where high-altitude trees profited from the higher temperatures in 2003, while trees growing at low altitudes suffered from drought (Jolly et al. 2005, Leonelli & Pelfini 2008). However, this does not explain the negative growth response of silver fir in 1976, as the heat and drought in 2003 was even more severe than in 1976. However, climate in the years preceding the drought events differed considerably: while the years before 1976 were already characterised by precipitation deficits in summer, the years before 2003 were quite humid. In 2003, heat and drought came quickly and later in the growing season, resulting in an immediate growth stop at medium and low altitudes. Compared to the long-term average, the weather conditions at the high altitude were less extreme than the conditions at the medium and low altitude.

The annual radial growth responses of the studied low-altitude silver fir and Norway spruce trees are not in line with the general growth reaction found in other low-altitude tree chronologies in the Black Forest after the 1976 summer drought, which is characterised by a deep growth depression and a 3-year recovery period. They also conflict with the notion that the drought susceptibility for both species is high at low-elevation sites (Desplanque et al. 1999, Mäkinen et al. 2002b, Rolland et al. 2000) and at south-exposed sites (Rolland et al. 2000). Possible explanations for this discrepancy include effects of age (higher plasticity), or of thinning. Namely, the h/d-values of the six dominant trees indicate that they were suppressed in the first part of their life, and released in the years before 1976. Release normally increases growth for some years. However, extreme dry weather conditions may affect this positive growth response (Spiecker 1986). Existing literature (Mäkinen et al. 2002a, Misson et al. 2003) does not provide unambiguous evidence about this phenomenon.

Additional data will be collected to analyse the underlying causes for the observed growth responses of silver fir. Growth data will be supplemented by cell structure analysis, as intra-annual tree-ring parameters (i.e. cell diameter, cell wall thickness, wood density) may provide information for a better understanding of the growth behaviour of trees (Park 2000, Park & Spiecker 2005). In addition, the available climate data will be analysed in detail (i.e. calculation of evapotranspiration and drought indices) to reveal how the trees experienced the warmth and drought in 1976 and 2003 at different altitudes and to derive estimates about tree-growth reactions related to a different seasonality of drought events expected by climate change scenarios for the future.

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# Age and susceptibility of Fennoscandian mountain birch (*Betula pubescens*) towards insect outbreaks

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## Introduction

*Epirrita autumnata* is one of the few Lepidoptera species that regularly reaches outbreak levels in northernmost Fennoscandia (e.g. Bylund 1997), where mountain birch (*Betula pubescens*) is the dominant tree species (Tenow et al. 2004). *E. autumnata* has a very high potential population growth rate (6 to 10-fold in one generation, Bylund 1995) and its leaf-eating caterpillars may cause massive defoliation over large areas (Tenow 1972, Karlsson et al. 2004). To reach outbreak level, at least three consecutive years of population growth are needed (Virtanen et al. 1998). High reproduction rates are mainly prevented by cold winter temperatures. The lethal temperature for the eggs is -36.5 to -35.1°C in high winter (December and January) and -29.8 to -28.3°C in late winter (February to April) (Eckstein et al. 1991). These facts make the population dynamics of *E. autumnata* subject to regional climate change, and suggest that the frequency and abundance of outbreak events is likely to be enhanced in a warmer future.

Disturbances caused by *Epirrita* fundamentally affect the forested ecosystems along the Scandes range and may cause tree mortality and trigger rejuvenation if an outbreak occurs in an unfavourable growth season (Kallio & Lehtonen 1975). Severe defoliation (more than 80% loss of foliage) reduces the annual ring width considerably for one or more years (Hoogesteger & Karlsson 1992).

Tenow (1972) and Bylund (1997) discovered that the susceptibility of mountain birch towards defoliation was tree-age dependent during the biggest known event in 1955. Stand age does not directly influence larva mortality but mature trees are generally more attractive for adult insects because they offer more places for oviposition (Ruohomäki et al. 1997). The eggs have a higher survival rate if they are laid into cracks, lichens or on scarred surfaces. Therefore, trees older than 60 years generally suffered from more severe defoliation in 1954/55 than young individuals because the larval density was higher (Tenow 1972, Tenow 2004).

Here, we investigate for the first time the different impact of *Epirrita*-caused defoliation on radial growth in old and young trees along altitudinal transects and for the four most recent outbreak events in the research area. These took place in 1954/55 (Tenow 1972), 1986, 1994 and 2004 (Babst et. al. in prep.) and locally were of different intensity and distribution. In Babst et al. (in prep), the ring-width series of both transects was compared to local climate data in order to distinguish between outbreak effects and variability caused by changing growth season temperatures. Our goal in this study is to reinvestigate the connection between tree age and vulnerability towards insect outbreaks in terms of a general validity of the findings from the 1954/55 event. If the stand age structure is found to be a key parameter steering susceptibility, this has implications in forest stability and management with regard to a warming regional climate.

## Materials and Methods

### *Study area*

Research was conducted in the area of Lake Torneträsk (68°19'6''N, 19°16'44''E; 341m a.s.l.) and the Abisko National Park in Swedish Lapland. The region of interest is situated on the Eastern

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slope of the Scandes. There are two types of pure mountain birch (*Betula pubescens*) forest in the research area. Most slopes are covered by the dense meadow type whereas the lower areas are dominated by the heath type (Vegetationskarta 1981). Apart from small villages along the south side of the main lake, the area of interest is mainly unsettled. **Figure 1** shows a schematic view over the study area. Temperature and precipitation data available back to 1913 from the Abisko Scientific Research Station (ANS), which is located at the southern margin of Lake Torneträsk, characterize the cold and dry climate in this region. Despite the low annual precipitation sum (304 mm) due to the lee setting, water is not a limiting factor to tree growth. The average annual air temperature is -0.55°C and mean summer temperature (JJA) is 9.98°C allowing tree growth up to about 650m a.s.l. Mean JJA temperature is the most important factor steering tree growth. Together with natural growth variability, summer temperature accounts for 80% of the variance in detrended ring-width series (Eckstein et al. 1991, Karlsson et al. 2004). Strong growth-climate relationships allow disturbances to be identified as significant deviations from temperature modelled growth.

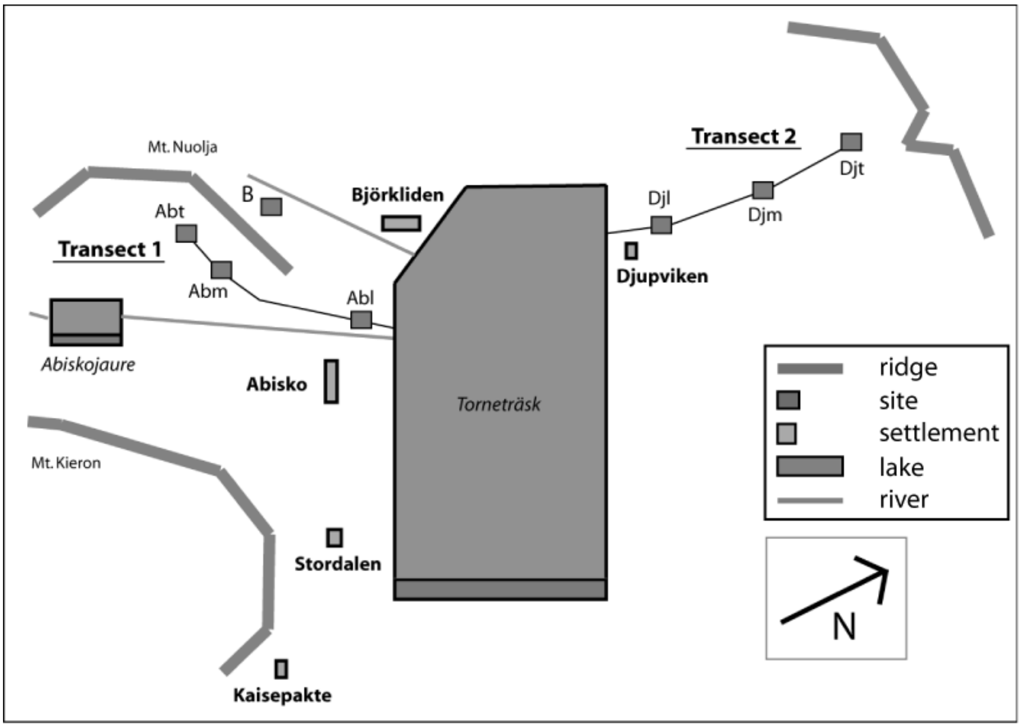

Figure 1: Schematic view over the research area. Transect 1 (Abisko) is located south of Lake Torneträsk, Transect 2 (Djupviken) covers the slope above its north-west end.

### *Sites and chronologies*

Samples were taken along two transects with three sites at different elevations each (see **Figure 1**). This sampling strategy accounts for a potential impact of elevation on the susceptibility of young and old trees towards insect outbreaks. Transect 1 (Abisko) with the sites Abl (low), Abm (middle) and Abt (top) was set up south of Lake Torneträsk on the east-facing slope of Mt. Nuolja. Transect 2 (Djupviken, sites Djl, Djm and Djt) is located at the south-facing slope above the north-western end of the main lake. At each site, increment cores from 18-20 trees (four radii per tree) were taken and later measured, crossdated, and detrended in order to produce reliable site chronologies. For this purpose, the programs COFECHA (Holmes 1983) and ARSTAN (Cook & Holmes 1986) were used and 50-years smoothing splines (Cook & Peters 1981) applied in order to remove low-frequency trends and preserve short-term variation. Additionally, variance was adjusted (Cook & Peters 1997) to avoid biases due to replication and cross-correlation changes during the calculation of arithmetic means (Frank et al. 2007). **Table 1** provides some basic information on series length, mean inter-series correlation (R-bar), expressed population signal (Wigley et al. 1984) and the number of radii from main and side stems (in case of polycormic individuals) included in each site chronology.

Table 1: Inventory of the curves included in the chronologies of the individual sites. Length of the chronologies with a replication >5 trees and EPS > 0.85. Additionally, the R-bar is displayed.

| Site | Length of Chronology | R-bar | EPS | Number of trees | Number of radii (main-stem) | Number of radii (side-stem) |
|---|---|---|---|---|---|---|
| Abl | 1915-2007 | 0.67 | 0.93 | 13 | 46 | 13 |
| Abm | 1900-2007 | 0.53 | 0.91 | 12 | 30 | 18 |
| Abt | 1971-2007 | 0.71 | 0.97 | 17 | 66 | 21 |
| Djl | 1939-2007 | 0.71 | 0.94 | 11 | 26 | 3 |
| Djm | 1877-2007 | 0.59 | 0.92 | 15 | 35 | 1 |
| Djt | 1950-2007 | 0.49 | 0.92 | 22 | 40 | 4 |

*Analysis of age and vulnerability*

Potential differences in the reduction of radial growth in old and young birch individuals due to an *Epirrita autumnata* population peak were investigated. As proposed by Tenow (1972) and Bylund (1997), a threshold age of 60 years at the time of the outbreak was considered, allowing young and old trees at all sites (except Abt) to be separately analysed. **Table 2** provides information about the number of young and old individuals at each site. Since the number of trees in each age class was not sufficient at all plots, the chronologies of equal elevations were combined to ensure a suitable replication. Additionally, possible bias induced by differing site properties is reduced.

Table 2: Number of young and old birch trees (threshold age 60 years in 2004) at the individual sites at both transects. The total number of the combined sites and the average age in 2004 are displayed.

| Site | No. trees > 60 years | No. trees < 60 years |
|---|---|---|
| Abl | 9 | 4 |
| Abm | 11 | 1 |
| Abt | 0 | 18 |
| Djl | 6 | 6 |
| Djm | 8 | 9 |
| Djt | 8 | 16 |
| **Total low** | 15 (av. age 89) | 10 (av. age 45) |
| **Total mid** | 19 (av. age 140) | 10 (av. age 38) |
| **Total top** | 8 (av. age 130) | 34 (av. age 29) |

A superposed epoch analysis was carried out which covered the four most recent outbreaks in 1954 (Tenow 1972, Bylund 1997), 1986, 1994 and 2004 (Babst et. al. in prep.). The correct dating of the outbreaks was ensured by calculating residuals from instrumental temperature data and from non-host species (not shown here). This way, the possibility of reduced growth due to unfavourable conditions was excluded. Three years preceding and following each outbreak were included in order to visualize the differences in reduction of the tree-ring indices between young and old trees during an outbreak. This analysis also enabled the inter-comparison of the four events in terms of intensities and recovery periods.

## Results

The reduction in radial growth due to insect outbreaks was compared for old and young birch individuals. Despite the present noise in the data, a distinct defoliation signal was clearly visible in all outbreak years. Generally, the impact of the disturbance appeared to be dependant on age, as well as elevation.

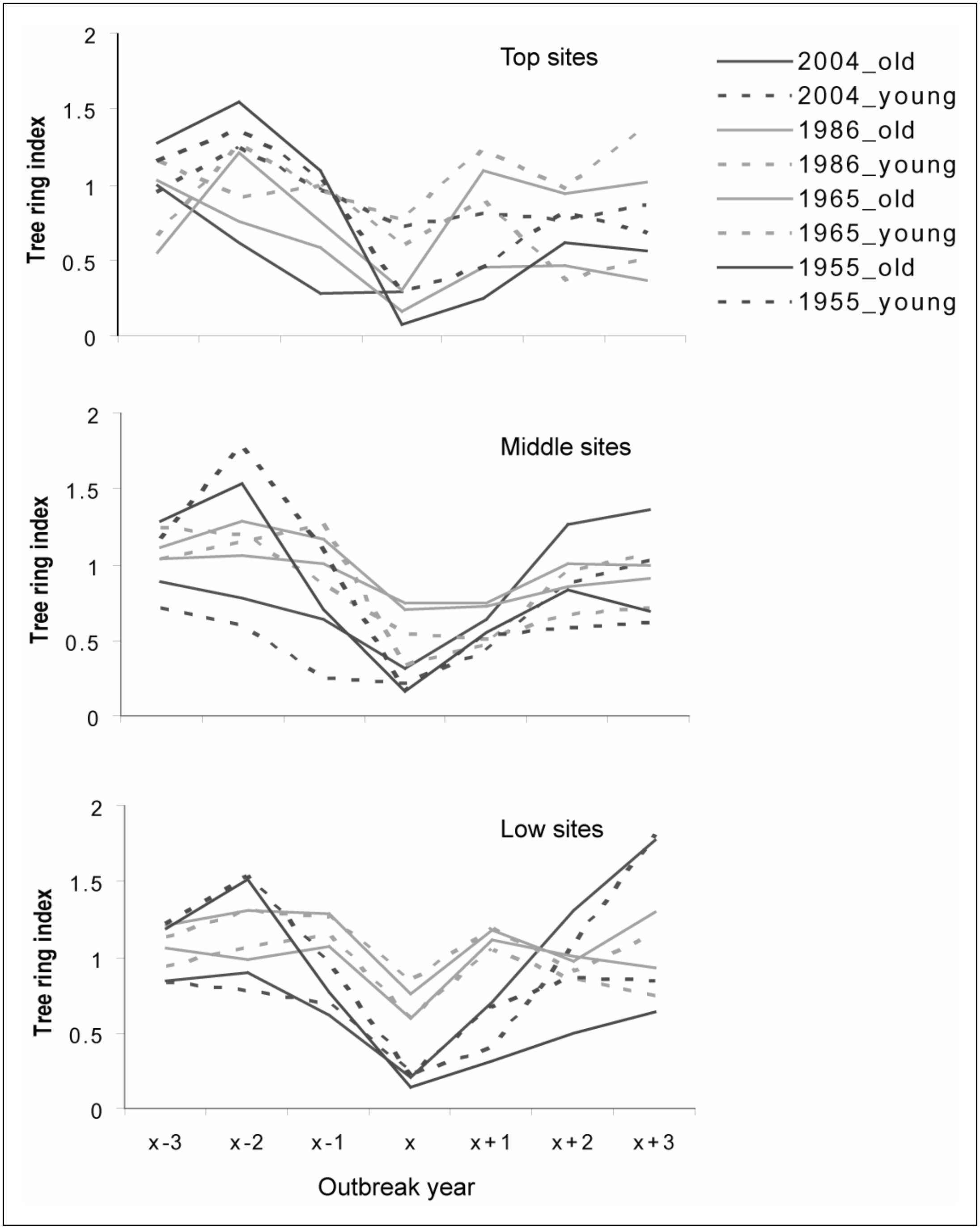

Figure 2: Superposed epoch analysis of the four most recent *Epirrita autumnata* outbreaks (1954/55, 1965, 1986, 2004). Tree-ring indices of three years preceding and following an outbreak event are displayed. Young trees are marked with dotted lines, old trees with continuous lines.

At the low-elevation sites, the difference in the intensities of the *Epirrita* population peaks is clearly visible (**Figure 2**). The absolute radial growth during the 1954/55 and the 2004 event were lower than the in 1965 and 1986. In terms of the age classes, no clear difference in the susceptibility was found in the outbreak years themselves. The recovery period after the 1954/55 event, however, appears to have been significantly longer for old individuals whose growth remained low in three consecutive years. On contrary, young birches approached purely climate determined growth already one year after the outbreak. After the large 2004 event, young trees appeared to have taken one year longer to recover than old individuals. The difference between the age classes, however, was less pronounced than after the mid-century outbreak.

At mid-elevation, again the 1954/55 and the 2004 population peaks led to the strongest growth reduction. Young and old birches were equally affected and showed similar recovery patterns. For the moderate 1965 and 1986 outbreaks, there is a clear difference in the reaction of the two age classes. In 1986, young trees reduced growth more strongly than old trees which produced nearly average ring-width. The ring-width reduction in the young individuals was as strong as during the two severe events. The growth pattern of the 1965 defoliation was similar to 1986, though less pronounced.

The tree-line sites showed a clear age-dependence of the *Epirrita*-caused damage. During all four most recent insect outbreaks, old trees reduced growth much more strongly than young individuals who, apart from the 1954/55 event, grew almost averagely. Despite the different general intensities of the events, which became evident at the low- and mid-elevation sites, the old tree-line birches were equally affected during all four outbreaks. Growth remained low for several years after the 1954/55 and the 2004 events. Furthermore, it became evident, that – for some unknown reason - the trees older than 60 years already suffered reduced productivity prior to the 2004 incident. None of them survived the heavy defoliation which matches the observations during field work.

## Discussion

Dendrochronological analysis proved an ideal tool to assess the degree of growth reduction in old and young birch trees due to insect outbreaks. Earlier investigations (e.g. Tenow 1972, Bylund 1997) suggested that old individuals generally suffer heavier defoliation since they offer more suitable places for oviposition and therefore are more attractive for female *Epirrita autumnata*. Our results confirm these findings only partly. While they assess the different intensities of the outbreak events correctly (Karlsson et al. 2004, Eckstein et al. 1991), they indicate that, apart from age, defoliation intensity strongly depends on elevation. At the lowest sites, young and old trees are equally defoliated during moderate and severe events. The top sites on the other hand, show distinctly heavier damage to older individuals. These findings indicate that the vulnerability of old birches increases towards the treeline where growth conditions are already harsh due to climatic circumstances. This is confirmed by the longer recovery phases and by the fact that none of the elder individuals survived the 2004 outbreak at the top site, whereas all of them recovered at middle and low elevation. The low growth of old trees prior to 2004 suggests that – for some unknown reason – trees have been weakened in advance which is likely to have promoted mortality in the outbreak year itself. Analysis of defoliation intensity (Babst et. al. in review) indicated that the top sites were equally or less disturbed than the lower parts of both transects.

When analysing these results, it is important to consider the differing replication and average age at both transects. The Abm site has only one young tree for the most recent outbreak in 2004, whereas the Abt site contains no old trees at all. This puts more weight onto the age classes of the Djupviken transect. Although the site properties at equal elevations do not differ considerably, the varying age distribution could slightly alter the tree-ring indices. For the 2004 event, the average age of the "old tree" category differed by 51 years between the low and the mid sites. However, no substantial difference in susceptibility towards insect-related defoliation is to be expected due to this age differences (Tenow 1972). Additionally, other disturbing influences like reindeer grazing (Stark et. al. 2007) may not be excluded. However, the consistent patterns found in this study, suggest that these biases are rather small. Furthermore, the considerable noise in the data which is likely to be caused by local differences in the *Epirrita* population density within the transects, did not prevent a conclusive interpretation of the results.

Another forest Lepidoptera species that reaches outbreak population levels is the larch budmoth (LBM, *Zeiraphera diniana*). Esper et. al. (2007) developed a 1200-year reconstruction of LBM outbreaks in the Swiss Alps. Similar to *Epirrita autumnata* (Ruohomäki et al. 2000), Esper et al. (2007) discovered a cyclicity in LBM population peaks every 9 years until 1981. The absence of mass outbreaks since the 1980s to the present is explained by the exceptional warming trend (Büntgen et al. 2005) disturbing the moths population cycle. In the case of *Epirrita autumnata*, a regional warming is likely to have the opposite effect. *E. autumnata*'s abundance is limited by egg-killing winter temperatures (Hoogesteger & Karlsson 1992) which suggests that outbreaks are likely to become more frequent and expand into hitherto unaffected areas (Klemola et. al. 2006, Tenow & Nilssen 1990). Such differing impacts of regional climate warming on related species complicate the prediction of the ecological consequences of a changing climate in Europe.

## Acknowledgements

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# The pathway of oxygen isotopes from soil to wood (Lötschental, Swiss Alps)

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## Introduction

Oxygen isotopes in tree rings are seen as a powerful tool for the reconstruction of past atmospheric conditions such as the isotopic composition of precipitation (Danis et al. 2006; Saurer, Borella & Leuenberger 1997b; Robertson et al. 2001; Anderson et al. 1998), air temperature (Libby et al. 1976; Rebetez, Saurer & Cerubini 2003; Saurer, Cherubini & Siegwolf 2000; Burk & Stuiver 1981; Edwards et al. 2008), precipitation amount (Masson-Delmotte et al. 2005; Treydte et al. 2006, 2007; Reynolds-Henne et al. 2007; Saurer et al. 2008), relative air humidity (Saurer et al. 1997b; Robertson et al. 2001; Ramesh, Bhattacharya & Gopalan 1986; Edwards et al. 2008), or even atmospheric circulation patterns (Miller et al. 2006; Roden & Ehleringer 2007; Welker, Rayback & Henry 2005).

Although the direction of the trees' response to these variables may be robust among species, sites and regions (Treydte et al. 2007; Saurer et al. 2008), uncertainties still exist regarding the spatial and temporal stability of the climate signal (Treydte et al. 2007; Reynolds-Henne et al. 2007). These uncertainties arise from the complex interplay between signals carried in the source water taken up by the roots and those produced by evaporative enrichment and (post-) photosynthetic processes at the leaf level and during downstream metabolism. Therefore, a deeper understanding of the contribution of all potential fractionation and exchange steps occurring on the way through the tree into the tree-ring is a prerequisite for a reliable interpretation of this environmental proxy.

With this study we aim to follow the complete pathway of oxygen isotopes from precipitation to the tree ring over the growing season under varying environmental conditions. We present weekly resolved records of xylem and needle water, phloem sugars and stem wood $\delta^{18}O$ of *Larix decidua* Mill. growing at two different altitudes in the Loetschental/Swiss Alps. These data are related to external variables such as precipitation and soil water $\delta^{18}O$, temperature, relative air humidity and vapour pressure deficit. By following the complete pathway of oxygen isotopes from precipitation to the tree ring over the growing season under varying environmental conditions, we find the source (soil) water $\delta^{18}O$ to be the main controlling factor for tree ring $\delta^{18}O$.

## Material and Methods

Our study region is the Loetschental, an inner-alpine dry valley in the Swiss Alps where two sites are located, one at the upper tree line (2100m asl, 46°23'58N, 7°44'34E, SSE) of a south-facing slope and the other at the valley bottom on a rocky hill (1350m asl, 46°23'29N, 7°45'38E, NNW). Hydrological conditions are generally dryer at the valley site which receives less precipitation and thus has lower soil moisture conditions than the upper site. Soil types are similar at both sites with about 60cm depth from the surface to the bedrock and were classified as podzolic cambisols.

At both sites we selected four larch (*Larix decidua*) trees growing in open stands, so that every individual was directly exposed to sun. Development of phenological stages over the vegetation period was recorded by observing bud break, needle maturing, yellowing and fall. Sampling took place weekly from 7 April 2008 (week 15) until 11 November 2008 (week 46) and also diurnally at three sampling dates (Boda et al. 2009). To obtain samples of xylem water, needle water and phloem sugars, we cut three twigs per tree at different heights of the sun exposed crown and separated them into needles, bark and wood. Needle and xylem water was gained by cryogenic vacuum extraction at the Paul Scherrer Insitut (Ehleringer et al. 2000). Phloem sugars were extracted by successive pipetting and drying the solution at 65°C in silver capsules (Boda et al. 2009).

At the end of the vegetation period, we took 10mm tree cores from all sampled trees at breast height to determine cell widths of the actual tree ring. Tree cores were cut into 20µm sections and assigned to the corresponding week of formation by applying a growth model (Gompertz function). This model was generated from the growth rate of four other trees at the same site, for which the amount of cell enlarging, wall thickening and mature cells was determined by taking micro cores on a weekly basis (Rossi, Deslauriers & Morin 2003).

Additionally precipitation (rain collectors) and soil water in 10cm and 60cm depth (tension lysimetry) was sampled weekly following standard procedures to minimize evaporation between sampling periods (Thimonier et al. 2005; O'Driscoll et al. 2005; Boda et al. 2009). Due to rather dry conditions at the lower site, relatively few water samples were collected.

Isotope measurements were carried out at the WSL (Soil and precipitation water; Delta V Advantage mass spectrometer, Gasbench II, Thermo-Finnigan), the PSI (xylem and needle water, wood; Delta Plus XP mass-spectrometer; Thermo-Conversion Elemental Analyser TC/EA, Thermo-Finnigan) and the University of Trier (phloem sugars; Delta V Advantage mass spectrometer, Thermo-Conversion Elemental Analyser TC/EA, Thermo-Finnigan). The overall analytical precision, estimated from periodic standard deviation of commercial standards was ±0.2‰ for water samples, ±0.3‰ for wood samples. All data is referenced to VSMOV and given in ‰ as deviation from the standard.

At both sites air temperature and relative humidity data at 15 minute resolution were measured in the stands using HOBO pro v2 sensors (U23-002) starting at the beginning of the 2008 growing season. For analysis of the seasonal cycle, weekly mean/maximum values were calculated.

## Results

### *Seasonal patterns in* $\delta^{18}O$

There is a marked decrease in $\delta^{18}O_{xylem}$ at the beginning of the vegetation period, partly followed by $\delta^{18}$Oneedles and $\delta^{18}$Ophloem. This pattern is surprising and contradicts the trend that would be expected by the influence of isotopically depleted snowmelt water (Robertson et al. 2001; Treydte et al. 2006). Since the water flow through the deciduous Larch trees should be interrupted in winter times, we hypothesize a coupled effect of water storage from previous autumn (Waring, Whitehead & Jarvis 1979; Brandes et al. 2007) and additional enrichment due to evaporation effects in the twigs (Dawson and Ehleringer 1993). This assumption is supported by phenological data, since needles mature and start with full stomatal transpiration roughly when source water and xylem signals become coupled again. Since we hypothesise that this trend is not related to the current year processes of interest, we excluded all early values, before the minimum, from our correlation analysis.

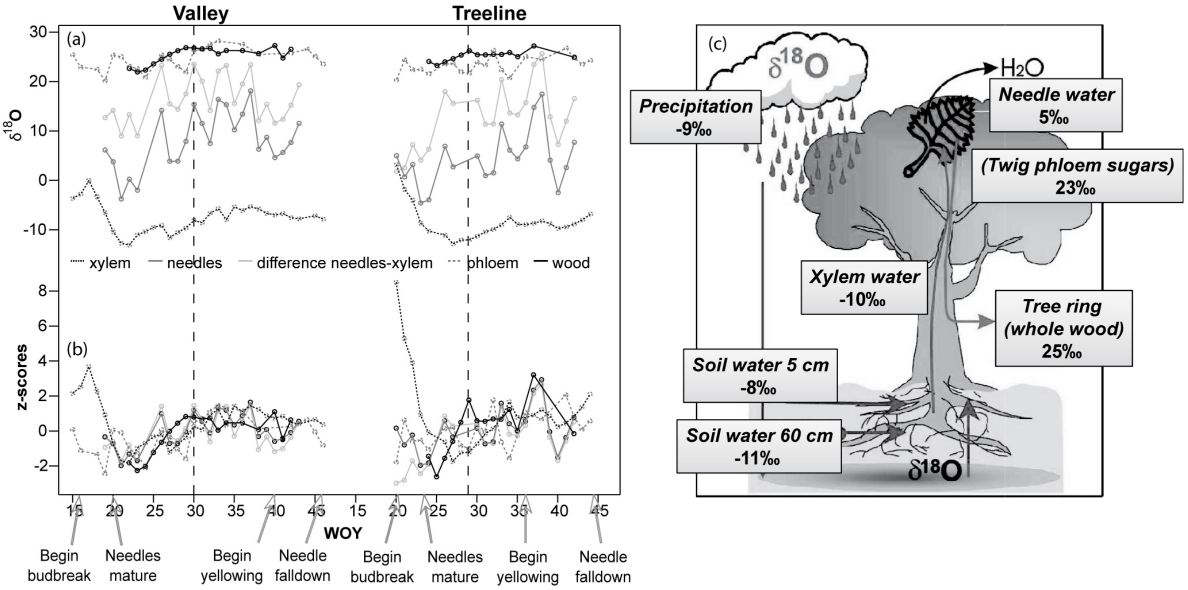

*Figure 1: Seasonal $\delta^{18}O$ variations per site and parameter and distribution of mean values within the tree*
*a) Comparison of absolute values $\delta^{18}O_{xylem}$, $\delta^{18}O_{needles}$, the difference $\delta^{18}O_{xylem}$- $\delta^{18}O_{needles}$ and $\delta^{18}O_{tree\text{-}ring}$*
*b) Normalized data of the same parameters. Dotted lines represent the transition between early and latewood*
*c) Mean $\delta^{18}O$ of all tissues over the whole growth period 2008 (May-October) at the treeline (2100 m asl)*

At the valley site, a mean inter-series correlation of r=0.58 ($p<0.05$) between the tree parameters points to a common signal contained, with highest dependency of needle water on xylem water variations (r=0.67, $p<0.01$). If the source water trend is removed from the needle water ($\Delta^{18}O_{needles}$), any accordance to the other tree internal parameters disappears, indicating little influence of the leaf water enrichment on phloem and tree-ring values. Normalized records (Fig. 1b) indicate that these correlations are mainly created by a common long-term trend rather than by short-term variations. At the treeline, such a common trend is less obvious. There, $\Delta^{18}O_{needles}$ shows even a negative correlation to $\delta^{18}O_{xylem}$ (r=-0.53, $p<0,05$), which seems to be induced by the strongly decreasing trend of $\delta^{18}O_{xylem}$ in the beginning of the vegetation period, coincidently with an increasing trend of needle water enrichment. The strong common signal at the valley site suggests a fast and continuous transfer, in contrast to more diffuse patterns at the treeline. A reason could be that low temperatures partly decelerate the tree metabolism and therefore lead to stronger but not uniform time lags. Figure 1c visualizes the change in the mean growing season $\delta^{18}O$ values along the whole $\delta^{18}O$ pathway for the tree-line, where also continuous records of soil water $\delta^{18}O$ are available.

### *Signal transfer*

At our sites in the Loetschental, short-term $\delta^{18}O_{soil}$ variations are only partly explained by precipitation variations whereas both contain similar long-term trends, particularly in the first half of the growing season (Fig. 2a). This overall increase can easily be explained by a successive transition from snowmelt to liquid precipitation and increasing temperatures, which is metachronous between the two sites. Later in the season, soil water seems to show a delayed response, particularly to one negative $\delta^{18}O_{ppt}$ peak in week 34 at the tree-line, which also could result from a snowfall event that dominated the water sample of this week. With our sampling intervals, however, we were not able to appropriately estimate these time lags in more detail.

$\delta^{18}O_{xylem}$ consistently lies between the values of both soil layers, suggesting a predominant use of surface water under shallow soil conditions. Additionally, a certain residence time of xylem water in the tracheids (Brandes et al. 2007), and the occurrence of considerable time shifts between water at the trunk basis and in the crown in coniferous species (2.5 - 21 days; Meinzer et al. 2006) can modify the absolute level of xylem values.

At the treeline, where soil water was available on approximately a weekly basis, $\delta^{18}O_{xylem}$ nicely follows seasonal trends in $\delta^{18}O_{soil}$ (Fig. 2a). Unfortunately, this clear dependency of xylem water on soil water variations at the treeline cannot be fully confirmed at the valley site, due to large gaps in the soil water records.

At both sites, needle water evaporative enrichment, with the xylem water trend eliminated, strongly reflects high and low frequency variations of meteorological variables (Fig. 2c), particularly relative air humidity (rH) and vapour pressure deficit (VPD). These effects can be easily explained by variations of the evaporative demand (Farquhar et al. 2007).

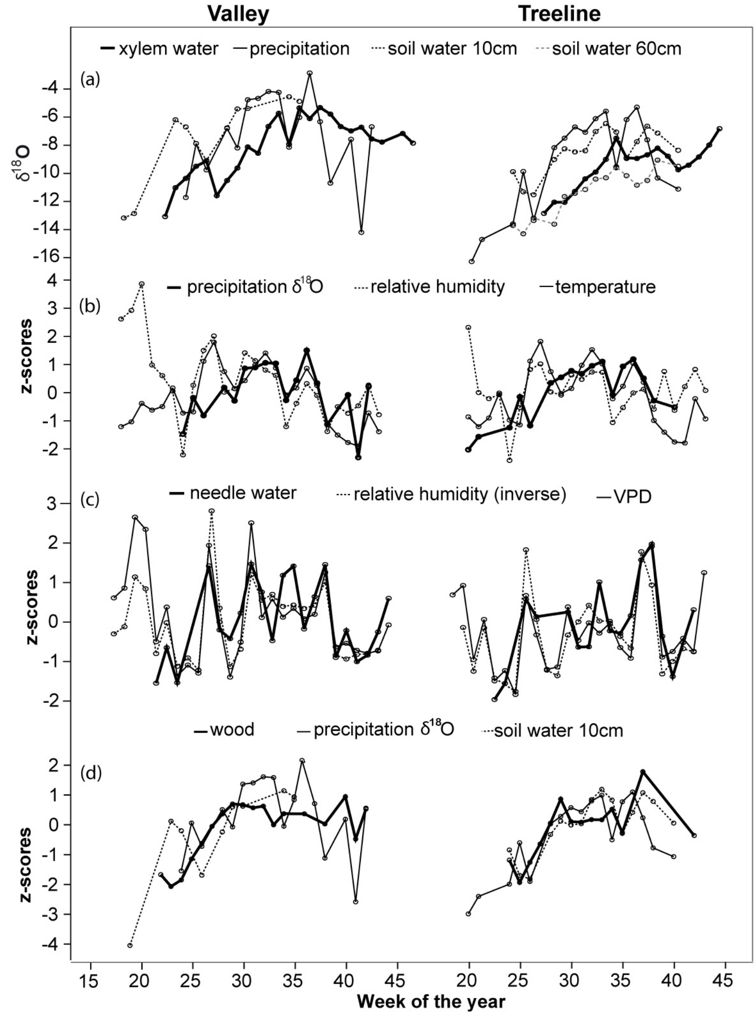

*Figure 2: Seasonal $\delta^{18}O$ variations per site and parameter*

Interestingly, daily maximum temperatures correlate with $\Delta^{18}O_{needles}$ at the valley site (r=0.65, p<0.01), but not at the tree-line. Only in the valley the soil water signal carried in the xylem is significantly fingerprinted in $\delta^{18}$Oneedles (r=0.60, p<0.01).

Unexpectedly, phloem sugars do not show any correlations to $\Delta^{18}O_{needles}$ despite strong seasonal variations at both sites. The mean offset between phloem sugars and xylem water of 31.7‰ (compared to 18.8‰ between phloem and needles) points to a substantial proportion of either twig assimilated sugars (Barnard et al. 2007) or a mixing of day sucrose with sugars from transitory starch breakdown during night. At least in the valley, $\delta^{18}O_{phloem}$ correlates with $\delta^{18}O_{xylem}$, $\delta^{18}O_{needles}$ and $\delta^{18}O_{tree\text{-}ring}$.

$\delta^{18}O_{tree\text{-}ring}$ at the tree-line is predominantly controlled by $\delta^{18}O_{soil\_10}$, explaining 72% of the variance. Particularly the increasing trend in the first half of the vegetation period is well matched (Fig. 2d). The correlation to $\delta^{18}O_{ppt}$ is lower, although still significant, and of similar strength as at the valley site (valley: r=0.58, treeline: r=0.59; $p<0.05$). At the valley site $\delta^{18}O_{soil}$ is not significantly correlated with $\delta^{18}O_{tree\text{-}ring}$ because of the soil water data gaps. Whereas short-term variations are weakly reflected and seem to be damped, the seasonal trend, also kept in soil water $\delta^{18}O$, nevertheless is mirrored. Additionally, there are correlations with $\delta^{18}O_{xylem}$, $\delta^{18}O_{needles}$ and $\delta^{18}O_{phloem}$ at the valley site and with $\delta^{18}O_{needles}$ at the tree-line. Interestingly, at both sites, any correlations to external variables (rH, VPD and T) that were found to dominate the needle water variations are insignificant and did also not improve when splitting the records in early and late wood, and calculating the correlations to external variables for both periods separately.

The fact that $\Delta^{18}O_{needles}$ is not correlated to $\delta^{18}O_{tree\text{-}ring}$ means that seasonal source water variations clearly dominate over physiological processes at the leaf level. During wood synthesis, part of the oxygen atoms exchange with xylem water, reducing the influence of needle water enrichment and retrieving some of the source water signal. This exchange was reported to be about 42% for cellulose (Sternberg et al. 1986; Sternberg et al. 2003; Roden et al. 2000). Based on Barbour et al. (2007), we calculated an exchange of whole wood of 40% at the valley and 21% at the tree-line, the latter value being much lower than it would have been expected for cellulose. This could be related to a different proportion of oxygen atoms exposed to exchange with medium water in whole wood compared to cellulose. This points to a stronger contribution of downstream metabolic processes than at the treeline.

Overall, our findings indicate that $\delta^{18}O_{tree\text{-}ring}$ predominantly records the source water information, which partly relays on xylem water preserved in the needles and partly on a post-photosynthetic exchange with medium water. Needle water enrichment and fractionation effects during assimilate production seem to be of lower relevance for the isotope signal in the wood. Consequently, the strength of the atmospheric signal recorded in the source water is most crucial for the application of $\delta^{18}O_{tree\text{-}ring}$ for climate reconstruction. $\delta^{18}O_{soil}$ in the Loetschental reflects the precipitation trend at both sites, albeit damped and with a certain time lag. Therefore, $\delta^{18}O_{ppt}$ is indirectly represented in $\delta^{18}O_{tree\text{-}ring}$ by explaining at least 33% to 34% of the variance. Since roughly half of the seasonal variation in $\delta^{18}O_{ppt}$ itself is explained by local weekly maximum temperature (58% at the valley site, 46% at the tree-line), being in the range of results of longer-term, inter-annual studies in Switzerland (Rebetez et al. 2003), the lack of correlation between seasonal $\delta^{18}O_{tree\text{-}ring}$ and temperature could be enhanced again on inter-annual scales, considering the integrating character of the tree ring.

## Conclusions

We investigated the seasonal pathway of oxygen isotopes from precipitation through several tree tissues into the tree ring at two altitudes in the Loetschental to estimate the influence of the source water and the stomatal signal under different ecological conditions.

Most interestingly variations in $\delta^{18}O_{tree\text{-}ring}$ at our sites are clearly dominated by the source water signal. This includes recent precipitation water and further water pools within the soil, from the beginning of cell development in spring. Although variations in needle water enrichment are strongly controlled by weather conditions during the whole growing period, they are not significantly fingerprinted in the tree ring and therefore are seen to be of low relevance in contributing to the overall tree ring $\delta^{18}O$ signal. This finding suggests low relevance of needle water enrichment and fractionation effects during assimilate production for wood synthesis.

The impact of plant physiological parameters seems to be independent of altitude and moisture conditions. However, we can state that cool conditions lead to a more diffuse short-term pattern of the oxygen isotope transfer within the tree, due to lower metabolism rate and resulting time lags in the response to meteorological and physiological impacts.

Overall, our findings have direct implications on future sampling strategies for climate reconstructions based on tree ring $\delta^{18}$O: They clearly suggest that the strongest climate signal should be recorded at sites, where soils are most frequently supplied with precipitation water during the growing period, namely in temperate regions under humid precipitation conditions with precipitation maximum in summer. This suggestion is supported by results from a European tree ring isotope network containing the strongest climate signal at temperate sites in the United Kingdom and Northern France (Treydte et al. 2007).

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# Air pollution recorded in Scots Pine growing near a chemical plant, preliminary results and perspective (Upper Silesia, southern Poland)

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## Introduction

Tree-ring analysis was frequently used to study the influence of industrial pollution occurring from the 19th century onwards on tree stands (Schweingruber et al. 1985). Many studies were carried out in the 1970s when air pollution emissions were particularly high. The studies were located near different sources of pollution (Ashby & Fritts 1972, Vinš & Mrkva 1973). The study of Thompson (1981) for example revealed different intensities of radial growth reduction of trees depending on their distance from the pollution source and the amount of pollution emitted to the atmosphere. Simultaneously it was demonstrated that the relationship between tree-ring width and climate was altered in trees growing near sources of pollution (Nash et al. 1975). A study carried out by Schweingruber et al. (1985) applied a new methodology based on analyzing pointer years and abrupt growth release. The study in the Swiss Rhone Valley (Canton of Valais), apart from showing the number, degree, spatial and temporal distribution of tree-ring growth reductions, allowed the result to be related to the condition of the tree tops. It was found that the impact of both a deterioration or an improvement in environmental conditions is evident a few years earlier in tree rings than the effect is visible in tree tops (Schweingruber 1985, Kontic & Winkler-Seifert 1987). In the last 20 years studies carried out in different parts of the world have often been located around individual emission sources of pollution, for example around a non-ferrous smelter in the Kola peninsula (Nöjd et al. 1996), surrounding a chemical plant near in the City of Oulu in Finland (Jämbäck et al. 1999), in the neighborhood of a metal extraction and processing plant in Norilsk, Russia (Ivshin & Shiyatov 1995), near a great urban and industrial centre in Poland (Krąpiec & Szychowska-Krąpiec 2001, Danek 2007), and around a copper smelter in Utah state, USA (Kennedy-Sutherland & Martin 1990). In addition to studies of the exposure of tree stands to pollution emissions based on tree-ring width analyses, fluctuations in wood density and heavy metal concentrations in rings have recently been used (Ferretti 2002).

The objective of the study was to assess the influence of the pollution emitted by the Chemical Plant in Tarnowskie Góry on the condition of pines growing in the vicinity of the plant.

## Tarnowskie Góry Chemical Plant history

The Tarnowskie Góry Chemical Plant has been in existence since 1922. It is located in closed pine forest on the site of a former steelworks and paper plant. In 1995, the Chemical Plant went into liquidation. Severe environmental pollution in the vicinity of the plant caused its recording on the list of the 80 greatest polluters in Poland in 1994. However, studies of the environmental impact of the chemical plant have so far only referred to the pollution of rivers, lakes and ground water. The chemical plant's impact on air quality has not previously been studied, largely due to the unreliability of the data available concerning the air pollution emitted during the plant's operation. The Tarnowskie Góry Chemical Plant principally manufactured barium compounds, hydrochloric acid, and hard carbon black (Biernacki 1983). Its operation has lead to the death of pine trees lying within a radius of about 1 km surrounding the plant. Although no pollution data are available, the amount of individual chemical compounds produced in Tarnowskie Góry Chemical Plants are

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existent. Additional information allowing to quantify the degree of the harmfulness of individual compounds were sourced from technicians who worked with these compounds. The first important part of manufactured compounds in the chemical plant focused on organic chemistry mainly carbon black producing. The second part were inorganic chemistry compounds, mainly the production of lithopone. Both black carbon and lithopone were especially harmful substances to the environment. Corrosive clouds containing naphthalene oil and anthracene oil were emitted to the atmosphere during the production of black carbon and great amounts of sulphur dioxide and hydrogen chloride were emitted during the production of lithopone. The greatest amount of black carbon was produced between 1955-1970, the maximum quantity of lithopone from 1965 to 1985 (Fig. 1).

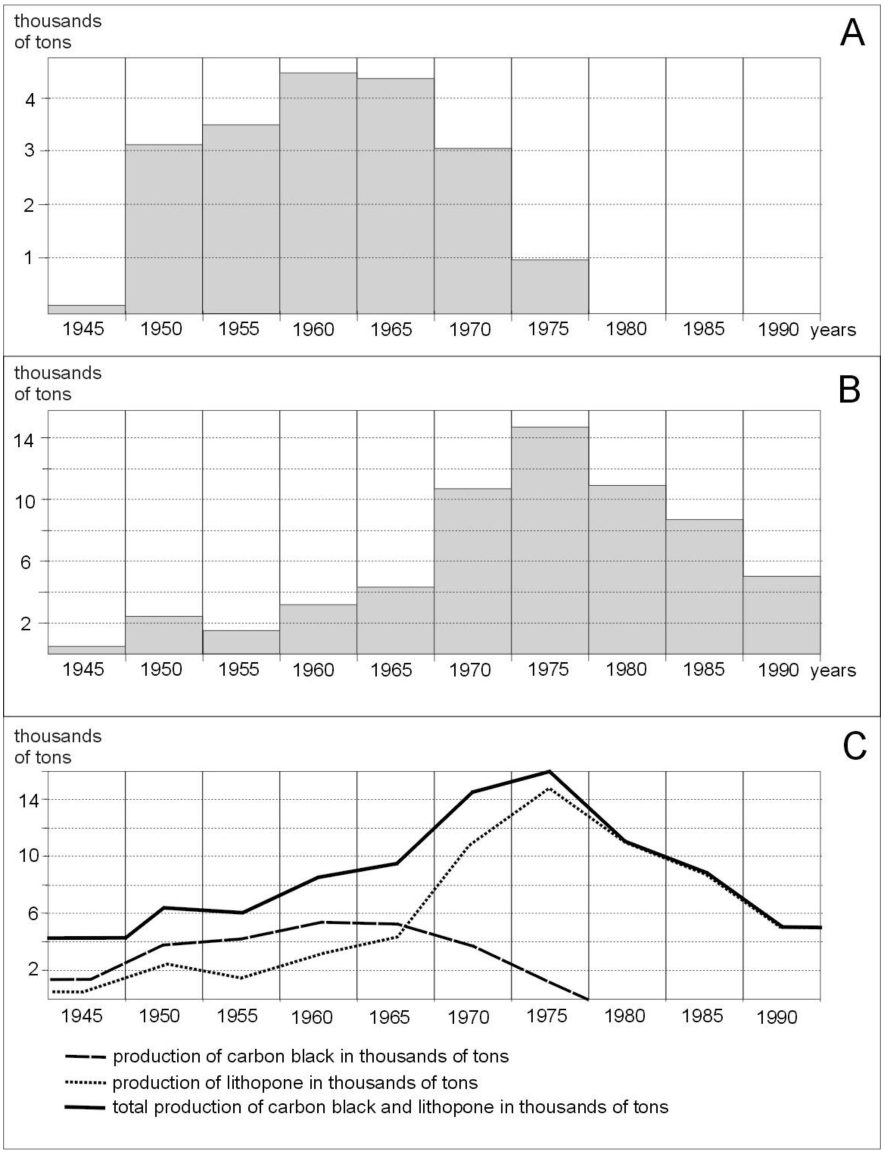

*Figure 1: The production volume at the Chemical Plant in Tarnowskie Góry (A – black carbon volume, B - lithopone volume, C – volume in total).*

## Tree sampling strategy and core study processing

Ninety-six cores were collected from pines growing on four sites situated 5 km from the plant. Cores were only sampled in an area with dry-mesic pine forest (Fig. 2a). After polishing the samples extremely narrow rings were found which had been produced in the 1960s and 1970s (Fig. 2b). Therefore the skeleton plot technique was used to find the missing rings. Next a chronology was developed for pines affected by pollution growing up to 5 km kilometres from the plant and in an area at least 20 km from the plant as a reference. The charts were compared so as to identify the influence of pollution on the annual rings of the trees.

*Figure 2: A -Typical site where samples were collected, B - one of the cores collected near the chemical plant with clearly visible ring suppression between 1950 and 1970.*

### Air pollution detected in tree rings - preliminary results

All of the pines studied which were growing within a 5 km radius from the Chemical Plant in Tarnowskie Góry produced suppressed annual rings between 1950 and 1980 (Fig. 3). There is evidence that the growth of these trees during the respective period was directly influenced by the amount of pollution emitted by the chemical plant in Tarnowskie Góry. Figure 4 clearly shows the inverse proportionality between the productivity of the chemical plant studied and tree-ring width.
The annual ring reduction was particularly significant in the 1960s and 1970s. The productivity of the plant quintupled from the 1950s to the 1970s and as from the 1930s to the 1970s it even increased by 15 times. In the case of pines growing 5 km from the plant, the annual rings produced in the 1960s and 1970s are on average ten times narrower than those produced earlier and after 1995. Missing rings have been identified in the ring sequences of these trees, particularly in the 1960s when the hydrochloric acid line was launched in the plant. Numerous annual rings for that period were missing from the record in the cores of more than half of the trees cored. This means that in this period the chemical plant was emitting a particularly large amount of pollutants. That period was marked by the use of new technology which led to the launch of new production lines and large emissions of air pollution. It seems that it was specifically the manufacturing of hydrochloric acid that was the main factor in the degradation of tree stands around the Chemical Plant in Tarnowskie Góry. Annual rings have been slightly larger since 1971 when hydrochloric acid production was discontinued, despite the increase in production of the remaining compounds produced at the Chemical Plant. The trees have not been producing strongly suppressed annual rings since 1982 when the production volume of the chemical plant started decreasing and environment-friendly technology started to be introduced.

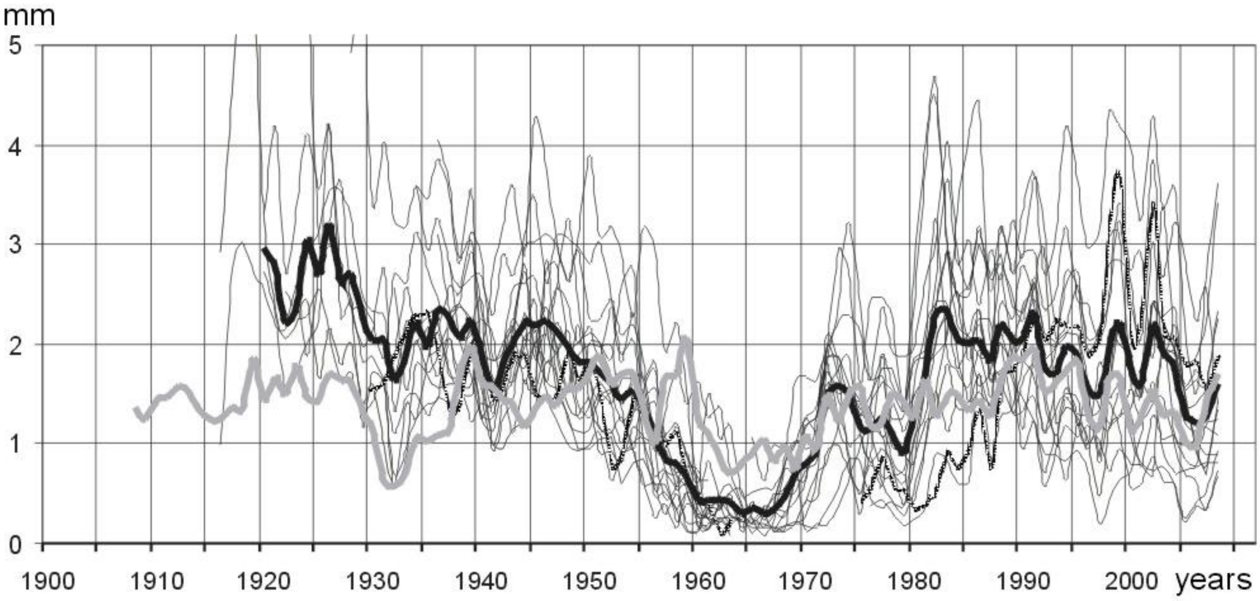

*Figure 3: Charts of annual rings together with local chronology from an area situated 5 km from the chemical plant (black colour) and a local chronology from an area situated 20 kilometres away (grey colour).*

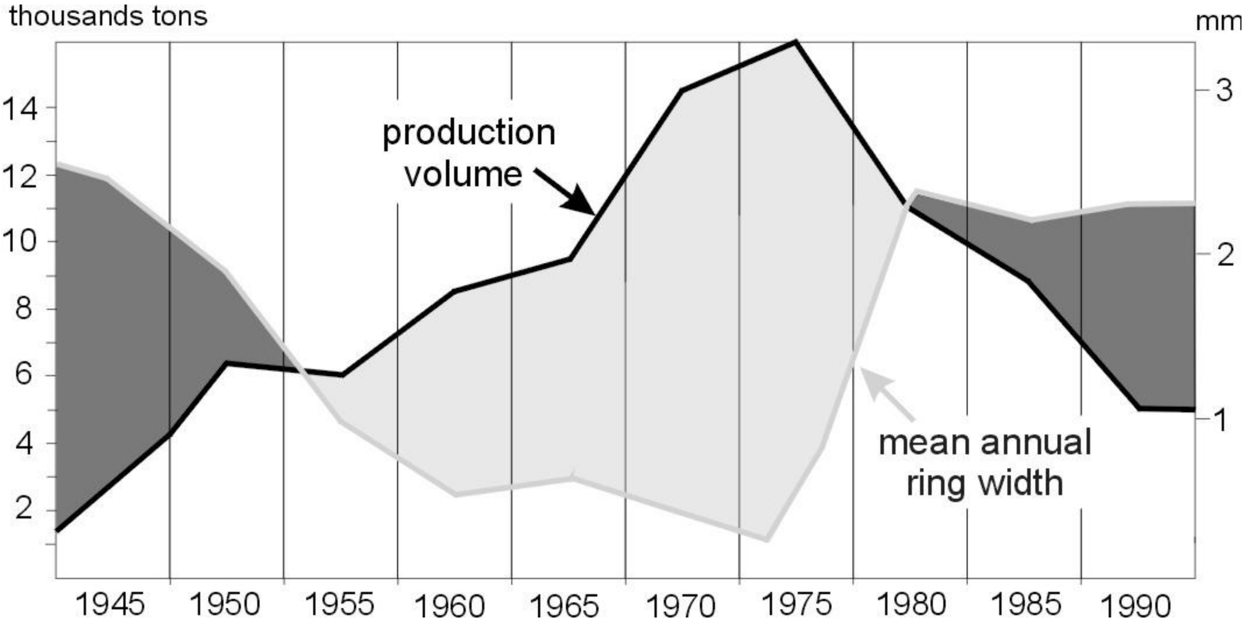

*Figure 4: A comparison of the production volume curve at the chemical plant (black curve) with the curve of annual rings (grey curve). The light grey area marks a period in which production increased and the annual rings were suppressed.*

### Air pollution detected in tree rings – perspective

In future, we plan to use statistical methods to detect what was the climatic control of the tree rings formed before, during and after the operation of the chemical plant. We will also study wood anatomical features at a time when rings were strongly suppressed to find anomalies controlled by the impact of the pollution.

A rise in the frequency of infant mortality, pulmonary cancer and other diseases was recorded in the town of Tarnowskie Góry. A high number of cases was observed during the 1960s and 1970s.

At that time samples from trees growing around the plant showed extremely suppressed rings. Based on this, we will try to find what was the impact of the emissions on the health of people living near the chemical plant at this time. We will use statistics to compare the periods with tree-ring reduction to periods with great pollution emissions to the atmosphere and the annual resolution of individual disease variability in the city of Tarnowskie Góry.

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# Physiological and growth response of European larch (*Larix decidua* Mill.) and pedunculate oak (*Quercus robur* L.) to environmental changes

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## Introduction

Predictions of the long term consequences of the rise of greenhouse gasses in the atmosphere on changes in tree growth and forest species distribution have been confirmed by several studies in Europe (Spiecker 1996, 1999, Makkonen-Spiecker & Kotar 1999, IPCC 2001). It has been stated that in the last decades tree growth has been changed especially on poorer soil sites, such as in upper timberline and in lowlands where forests compete with agriculture (Morison & Morecroft, 2006). Apart from forest management and land use, forest ecosystems are affected mostly by increased ambient concentration of $CO_2$, $NO_x$ emissions, air temperatures and precipitation distribution. Cumulative effect of climate changes should, according to the modelled estimates (Canell 1999), influence the growth especially on extreme sites.

Our study was oriented towards two forest ecosystems in Slovenia - in lowlands, where pedunculate oak forests are under severe agricultural pressure and where natural area of oak distribution is being reduced significantly by the different human activities (Wraber 1951), and at the upper timberline, where evident shift towards higher altitudes due to increased temperature and changed precipitation regime has been confirmed (Wieser et al. 2009). Recent studies suggest that reduction of natural area in lowland forests is in direct connection with agricultural activities and reduction of groundwater table (Levanič 1993, Čater & Levanič 2004). Changes in lowlands are reflected in decline of complete forest complexes, high mortality and uneven stand structure, accompanied by forest regeneration problems. Proportion of adult, vital forest stands is declining and sanitary cut increases due to physiological weakening and high mortality of oaks. Consequences are seen as an unbalance in the forest ecosystem and an increased susceptibility to weather extremes and pests. In the upper timberline growth conditions are, in comparison to lowlands, even more extreme and growing season shorter. Predicted temperature rise may affect the length of the growing season, vitality, regeneration and retention ability of the forest ecosystems at the upper timberline. Stability, survival and future existence of the upper timberline forest ecosystems may be in question.

Study and prediction of the tree response in disturbed forest ecosystems may significantly contribute to better guideline policies for the silvicultural and forest management practice in the changing environment in both stressed and stable forest ecosystems.

The objectives of our study were (1) to compare ecophysiological and growth response by adult trees of different vitality classes on marginal - extreme sites, and (2) to recognize and define tree response to rapidly changing growing conditions. In this paper we present preliminary results based on measurements from two research sites.

## Material and methods

Research areas were established at two different forest sites - pedunculate oak (*Quercus robur* L.) site in a floodplain area (156m ASL; 45. $8638^0$N, $15.4302^0$ E) and European larch (*Larix decidua* Mill.) site (1600m ASL; $46.3582^0$N, $14.7053^0$ E) at the upper timberline. At both locations, presence of both vital and declining adult trees was noticed on a small scale of a homogenous site. In our research, six dominant vital and six declining trees per species according to the ICP methodology (tree status assessed by the crown condition) were selected (Anonymous 2006). All study plots have been fenced (50x50m)., Ecophysiological response of trees has been recorded and compared with radial growth during three consequent vegetation periods (2007, 2008 and 2009).

Photosynthesis measurements were performed at a constant temperature of the measurement block ($20^0$C), a $CO_2$ concentration of 350 µmol/l, flow 500 µmol/s and different light intensities: 0, 50, 250, 600 and 1200 µmol/$m^2$s, as described in Čater and Simončič (2009). The measurements started at ambient light conditions that were reduced to reach zero, then followed by a gradual increase toward maximum values, so that stomata could be adapted. A-Ci curves were established to compare and define assimilation response of trees (A) to different intercellular $CO_2$ concentrations (Ci): measurements were performed at constant light 600 µmol/$m^2$s, humidity, constant block temperature $20^0$C and flow 500 µmol/s, while ambient $CO_2$ was varied as 0, 50, 100, 350, 700 and 1000 µmol/l. Maximal assimilation ($A_{max}$) rates and calculated compensation points (CP) for the light saturation and A-Ci curves were used in comparisons of trees between different plots. Both types of responses were measured with the LI-6400 portable system on at least three sun canopy locations per tree, located in the upper third of the tree-crown height on every plot.

Pre-dawn water potential (PWP) was used as a measure of static water stress-estimate in every tree. Samples were taken from the upper part of the crown using a water pressure chamber (Plant Moisture Vessel SKPM 1400, Skye, UK) (Larcher 1995). At least five repetitions were made on each tree in order to obtain a representative average value of PWP. Measurements were done once in a vegetation period at the same height as other physiological measurements. Water use efficiency (WUE) was calculated and compared between both groups of trees (Larcher 1995, Lambers et al. 1998).

Cores were taken from all 24 studied trees (12 oaks and 12 larches). Each core was mounted and sanded to a high polish following standard dendrochronological procedures (Stokes & Smiley 1996). Cores were then digitized using ATRICS® system (Levanič 2007) and annual radial growth measured to the nearest 0.01 mm using WinDENDRO™ software. Each tree ring series was then visually crossdated in PAST-4 using both visual comparisons and well established statistical parameters, including $t_{BP}$ (Baillie & Pilcher 1973), GLK% (Eckstein & Bauch 1969), and Date Index - DI (Schmidt 1987). Values of $t_{BP}$ greater than 6.0, GLK% values greater than 65% and DI values greater than 100 were considered significant. The ARSTAN programme (Cook, 1985; Cook and Holmes, 1999) was used to remove age trends in the ring width data and build site chronology. De-trending was achieved using a negative exponential or linear function. Indices were calculated as ratios between the actual and fitted values. Index values were then prewhitened using an autoregressive model selected on the basis of the minimum Akaike information criterion and combined across all series using bi-weight robust estimation of the mean to exclude the influence of the outliers (Cook 1985, Cook et al. 1990, Cook & Holmes 1999).

Indexed tree-ring widths were compared to meteorological data (mean monthly temperature and monthly sum of precipitation) from the nearby meteorological station.

## Results and discussion

### *Photosynthesis and water conditions*

Sensitivity of photosynthesis is similar for all $C_3$ plants and is in proportion with mesophyll $CO_2$ concentration (Farquhar et al. 1980). In view of climatic changes, numerous contradictory conclusions are being presented about the response of plants and future development to the environmental changes, especially due to temperature increase, decrease in the amount of precipitation and increase of atmospheric $CO_2$.

In all measured years, significant differences in light response between declining and vital trees have been confirmed for both larch ($p \leq 0.001$) and oak trees ($p \leq 0.01$) (Figure 1); however, differences in light compensation point, where production is balanced with consumption, were significant only between vital and declining oak trees ($p \leq 0.001$). Smaller absolute response to same light intensity in larch may be connected with species better adapted to the higher light intensities during the whole vegetation period. Comparison of response by maximal assimilation rate ($A_{max}$) to different $CO_2$ concentration between healthy and declining trees was also confirmed for both larch (declining: 8.2±1.3 μmol/m$^2$s; vital: 11.7±0.9 μmol/m$^2$s) ($p \leq 0.01$) and oak (declining: 7.8±1.2 μmol/m$^2$s; vital: 11.2±1.4 μmol/m$^2$s) ($p \leq 0.001$), while differences in $CO_2$ compensation points between the groups proved yet again significant only for oak trees ($p \leq 0.001$) (data not shown).

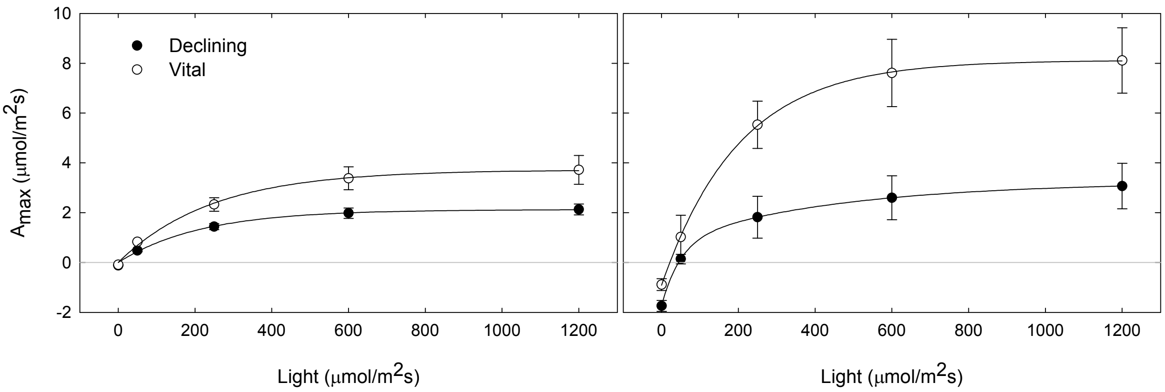

*Figure 1: Average assimilation response with standard error of mean in dependence to light intensity for larch (left) and oak (right).*

As part of the physiological measurements, pre-dawn water potential (PWP) was measured and water use efficiency (WUE) calculated. Both PWP (data not shown) and WUE were different for vital and declining trees in both species. WUE in vital larches was 1.95±0.4, in declining larches 3.12±0.7, in vital oaks 1.74±0.8, and in declining oaks 2.27±0.6 [μmol $CO_2$/m$^2$s)/(μmol $H_2O$/m$^2$s]), indicating that less water was consumed in declining trees for the same amount of carbon gain. Plants tend to reduce stomatal opening under water stress, so that WUE is maximized (usually at the expense of PNUE, photosynthetic nitrogen-use efficiency).

The measurements of assimilation response and water status (PWP) confirmed differences between both groups in both species, but did not indicate severe stress conditions in the group of declining larch trees. Oaks, on the other hand, growing on rich floodplain sites, do not exhibit loss of nutrients, but are affected by the water stress more severely in both groups. Maximal assimilation rate in the vital oak group (approx. 8-10 μmol $CO_2$/m$^2$s) was also below the measured response of healthy oaks (10-15 μmol $CO_2$/m$^2$s) on other comparable sites (Čater and Batič 2006), indicating that the vital oak group, too, is declared vital only in comparison with severely affected and almost dying oaks.

In spite of the relatively good insight into the carbon dynamics processes at the leaf level in changed $CO_2$ environment, it is difficult to make a prognosis of the future response by the whole plant also because of a short-time interval of observations and numerous possible interactions that have not been recognized yet (increased WUE might stimulate development of foliar fungi (Thompson and Drake 1994), while more sugars in assimilation apparatus may stimulate development of pathogens and infections (Hibberd et al. 1996) etc.). Recent research quotes up to 30% growth increase in the ambient with twice higher $CO_2$ environment (Medylin et al. 2001). Smaller probability that such increase would reflect in long-term assimilation was confirmed in the study, where growth increased only at the beginning, and was later reduced in time (Batič 2007).

*Radial growth and climate response of studied trees*

Both groups of the studied oak have been growing on the same site with same soil conditions differing only in groundwater table. On the site with declining oaks, groundwater level decreased after a road was built in 1938, which resulted in changed growing conditions (radial growth of oaks in vital and declining group) from that time on. Since 1938, vital oaks developed much wider tree-rings (2.70±0.48 mm) than declining trees (1.14±0.25 mm). Beside the differences in tree-ring widths, a significant difference in the year-to-year variability of tree-rings between both studied oak groups was also confirmed. Variability of the tree-ring width was much higher in vital trees than in declining trees. This indicates that the growing conditions for declining oaks were less favourable and that they were suppressed during the last 50-year period compared to the vital trees (Figure 2).

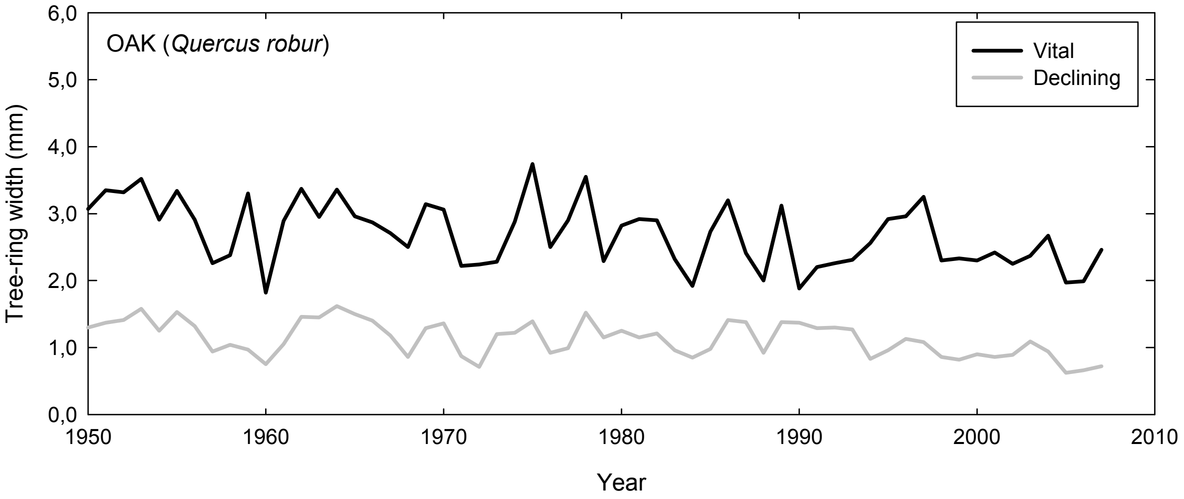

*Figure 2: Tree-ring widths in the group of vital and declining pedunculate oak trees (Quercus robur L.).*

Differences in radial growth in oak trees are more pronounced than in larch trees (Figure 3). We should expect tree growth on sites with soils consisting of high percentage of rocks and only organic horizons (larch site, upper timberline) more sensitive to the increasing temperature and also to water stress than on lowland oak sites. Vital larches had an average tree-ring width of 0.77±0.14 mm, and declining larches 0.52±0.12 mm, no significant changes in sensitivity or response to environmental factors were confirmed. According to the actual year by year growth, differences between the studied larch groups were small, which was also confirmed by ecophysiological studies.

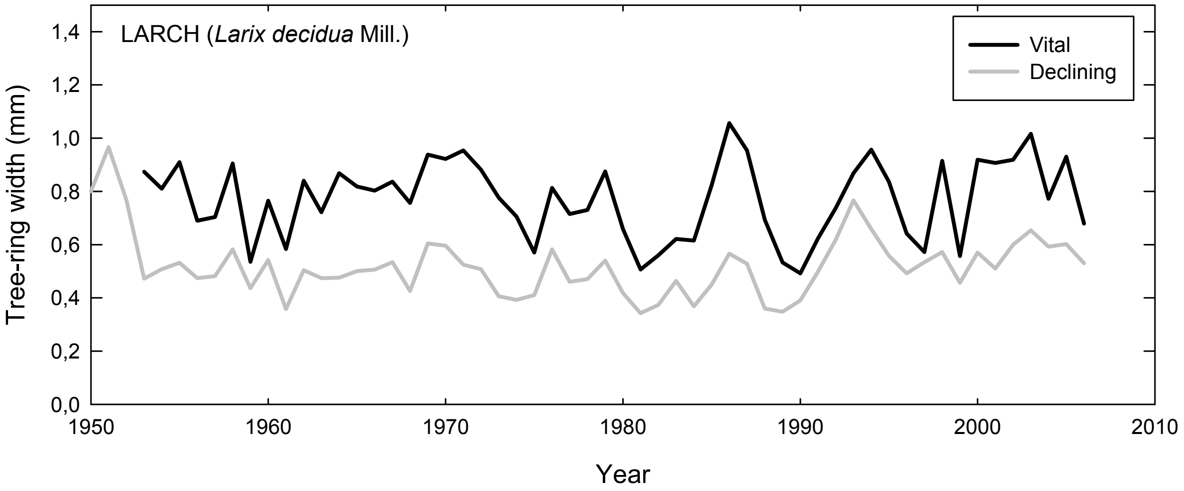

*Figure 3: Tree-ring widths in the group of vital and declining European larch trees (Larix decidua Mill.)*

Response of the studied trees to climate (Figure 4) differs significantly between sites and groups of trees. Growth of oaks in a floodplain forest depends mainly on the spatial and temporal distribution of the precipitation during the growing season. Vital oaks in floodplains responded positively to above average precipitation in May and June, while declining oaks with very narrow rings, usually consisting of only one row of vessels, responded negatively to above average temperature in March. Vital oaks show typical response of oaks in floodplain forests of Slovenia. In our case, the response of declining oaks was atypical, showing no response at all. Radial increment is too narrow to maintain the main role – conduction of water. Such trees are starving and are not able to respond to better growing conditions; their food reserves are limited and the only response to negative events is further decline of radial increment and even tree death (McDowell et al. 2008).

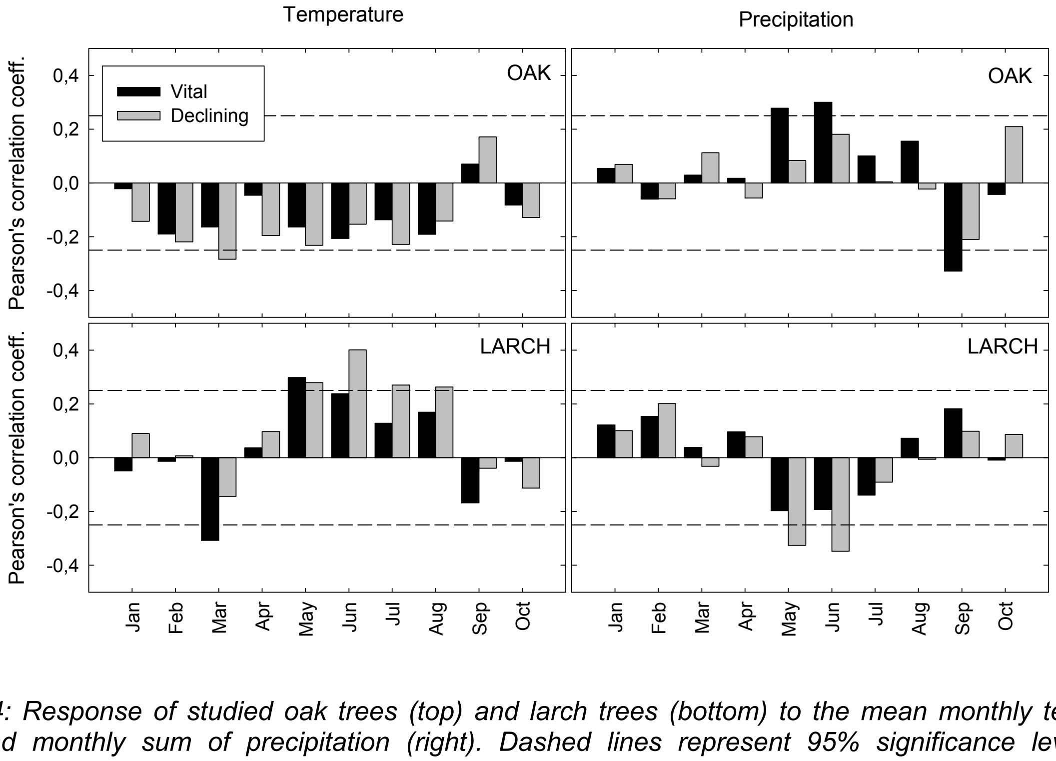

*Figure 4: Response of studied oak trees (top) and larch trees (bottom) to the mean monthly temperature (left) and monthly sum of precipitation (right). Dashed lines represent 95% significance level for the correlation coefficients.*

European larch at the upper timberline indicated a completely different response to climate than oak in the lowlands. Both groups of trees responded positively to above average temperature at the beginning of the growing season in May and June, which is in accordance with the findings of Frank and Esper for the European larch response to climate on the upper timber line (2005). Main difference between vital and declining trees is a short lag in their response. Vital trees start growing slightly earlier and are capable of taking advantage of the above average temperature in May, while declining trees start growing later. Above average temperatures in June have the most important influence on the formation of a wider tree ring in declining trees.

Precipitation has a more negative role at the upper timberline, since the greatest amount of precipitation in late spring falls as snow, which causes a considerable delay in the beginning of the growing season. It may also be connected with late frost events. Above average precipitation in May and June therefore negatively affects the growth on the upper timberline. Both groups of the studied trees respond similarly, with more intensive response to above average precipitation in declining group of trees than in vital trees.

## Conclusions

Oaks on plots with low water table are declining. Radial increments are small, responses to climate are evident only in the group of vital trees, while declining trees respond with a further growth decrease and finally die, as confirmed by our study. Declining trees are in more severe water stress and exhibit reduced transport function in xylem and roots; leaves lacking water transpire and assimilate less and the whole tree is subjected to a progressively physiological weakening. Responses of vital and declining trees at the upper timberline to microsite conditions are, contrary to lowland oaks, similar and in view of physiological response and radial increment very small. Weaker growing trees indicate a later response to above average temperatures during the vegetation period. Trees with bigger radial increment respond positively to above average temperatures in May and June (with emphasis on May); trees with narrower tree rings respond positively to above average temperatures during the same months as well, but with emphasis on June. Physiologically, the differences in assimilation rates are small and compensation points in both groups similar. Water stress is present, but not expressed as in the case of oak trees, where significant differences were confirmed in ecophysiological response regarding the maximal assimilation rates and compensation points for light and different $CO_2$ concentration. Pre-dawn water potential and water use efficiency were different for vital and declining trees in both species. In the case of larch, several positive pointer years were identified in hot and dry years (1960, 1976, 1988, 2003), showing that temperature at the upper timberline is one of the key limiting factors. Particularly dry and hot years, such as 1976 and 2003, had a significant positive effect on larch growth, while in lowlands their effect on oak growth was opposite. On the other hand, the cold and wet year 2005 had a positive influence on oaks and negative effects on larch tree growth. Despite the fact that a positive response of larch to temperature increase at the upper timber line was confirmed, such positive trends are questionable in the long term, because other environmental factors, such as mineral nutrition or amount and distribution of precipitation, may become limiting. Beside this, a rise of the upper timberline is only possible as long as soil conditions permit a shift upwards.

Oak forests in the lowlands are threatened mainly by the conversion o forest into agricultural land. Relatively small patches of the remaining forests are affected by the rapidly changing environmental factors. Oaks are stressed and physiologically weakened because climate change altered the relatively stable precipitation and flooding patterns. Radial growth of the studied trees has been declining since the late 1980's. Tree rings in vital oaks usually consist of 2-4 rows of early wood vessels and a significant proportion of latewood, normally more than 2 mm wide. The observed tree rings in declining oaks were very narrow, consisting of only 1-2 rows of vessels without latewood. Such declining trees are too weak to respond to favourable growing conditions, so their only response is a decline and an increased mortality.

## Acknowledgement

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# Coppice fingerprints in growth patterns of pedunculate oak (*Quercus robur*)

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## Introduction

Coppice is an ancient form of sustainable woodland management which provides both fuel wood as well as small-dimensional timber. The technique has been described as early as the Roman Era, amongst others by Cato and Columella (Meiggs 1982), but might be in use ever since the Neolithic age (Rackham 2003). It is a silvicultural system which relies on trees that are able to resprout after being cut periodically. With the decline in wildwoods over the ages, coppice management gained more importance, especially in the densely populated areas of North-Western Europe (Buis 1985, Vera 2000, Rackham 2003). Two important coppice systems are simple coppice and coppice with standards. In simple coppice, trees are grown as a single storey even-aged crop and cut after a certain period, defined as coppice cycle - the remaining stools form new sprouts which eventually replace the harvested poles. In the coppice with standard system there are different storeys. Next to the even-aged underwood there are taller trees - the standards - which are allowed to grow for several coppice cycles to provide timber. Coppice cycles normally differ between four and twenty-five years, depending on product, growth and demand (Boer 1857, Harmer & Howe 2003, Rackham 2003). One of the most important species used in coppice systems in North-Western Europe was pedunculate oak (*Quercus robur*) as it provided valuable tanbark as well as fuel wood and timber.

Nowadays, the reconstruction of past-woodland utilisation has become an interesting topic, especially in archaeology and landscape history. Different studies have been conducted on ancient wooden artefacts to derive information on past forest management (e.g. Billamboz 1990, 2003, 2008, Haneca et al. 2005). Small dimensional, even-aged wood with a limited number of annual rings (Fig. 1) is frequently found in excavations (e.g. Billamboz 2008, Haneca et al. 2005, 2006). Growth patterns in these wooden remains often reflect vigorous juvenile growth - wide rings around the pith – followed by a steep decline a few years later. Based on these observations, these wood remains are frequently categorised as originating from coppice systems (Spurk 1992, Haneca et al. 2005, 2006). If such growth characteristics are indeed indicative for coppice management, interesting information can be retrieved on past forest usage. However, no systematic study has yet been conducted to prove significant differences in growth patterns between trees from coppice systems and trees evolving from seeds. On the contrary, there are indications that the age trend in oak is not a reliable indicator of (past) forest management as climate, stand density and other environmental variables can have an overriding influence on the tree-ring pattern at least after some years (Copini et al. 2007a, b).

In this study, multiple generations of contemporary oak coppice (*Quercus robur*) in two nearby woodlands with similar soil types are systematically investigated, considering stem and stool densities and the social status of the stems, with a view to validating whether coppice management can be detected from juvenile growth patterns.

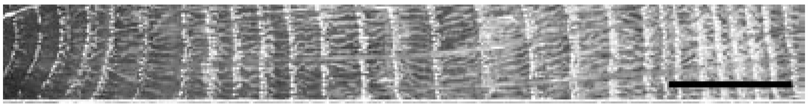

*Figure 1: Ring-width pattern of a cross-section from an archaeological excavation. The growth pattern shows wide rings and possibly reflects a coppice origin. The scale bar represents 1 cm (Source: Haneca et al. 2006).*

## Material and methods

### *Study sites and sampling*

The two selected woodlands Laarsenberg and Noordberg are located in the centre of The Netherlands at a distance of 12 km from each other and are both located on sandy soils (Fig. 2). In October and November 2008, different generations of coppice were selected in both woodlands – at the Laarsenberg three and at the Noordberg two generations (Tab. 1).

*Figure 2: Location of the woodlands Laarsenberg (L) and Noordberg (N) in The Netherlands.*

The number of coppice stools and sprouts per site (living and dead) was estimated by recording all stems and coppice stools in at least five randomly located 5-meter radius circles. Stem disks were taken at a height of 40 cm from 10 randomly selected dominant stems per site - only dominant stems were sampled to decrease variation due to different social positions. Furthermore, it is expected that dominant stems are more frequently used as timber and therefore more frequently found in excavations. The DBH and height of the selected stems were recorded. The stem disks were prepared using Stanley knives and razor blades. Ring width and earlywood (EW) width of two radii were measured and analyzed with a precision of 1/100 mm (LINTAB: Rinntech) in combination with TSAP software (Rinn 1996). To examine the age trends, the average radial growth was computed chronologically and according to cambial age.

*Table 1: Site characteristics of the coppice sites at the Laarsenberg and at the Noordberg.*

| **Coppice Site** | **Age/year of resprouting** | **Coppice stools per ha** | **Sprouts per ha living / dead** | **DBH ± SD (cm)** | **Stem height (m)** | **Ave. ring width ± SD (mm)** | **Ave. ring width first 5 yrs ± SD (mm)** |
|---|---|---|---|---|---|---|---|
| Laarsenberg 1 | 8 / 2001 | 1298 | 8225 / 0 | 3.5 ± 0.7 | 4.82 ± 0.33 | 2.47 ± 0.44 | 2.50 ± 0.35 |
| Laarsenberg 2 | 27 / 1982 | 1591 | 1957 / 2626 | 10.8 ± 2.3 | 12.22 ± 1.06 | 2.08 ± 0.86 | 2.59 ± 0.39 |
| Laarsenberg 3 | 32 / 1977 | 1564 | 1837 / 1601 | 16.6 ± 4.3 | 14.59 ± 1.86 | 2.76 ± 0.64 | 2.92 ± 0.20 |
| Noordberg 1 | 22 / 1987 | 1167 | 1655 / 2653 | 9.8 ± 2.4 | 9.77 ± 1.43 | 2.69 ± 0.81 | 2.13 ± 0.93 |
| Noordberg 2 | 29 / 1980 | 1167 | 1994 / 1528 | 13.8 ± 2.6 | 12.13 ± 1.31 | 2.31 ± 0.58 | 2.15 ± 0.47 |

## Results and Discussion

### *Characteristics of oak coppice in the woodlands Laarsenberg and Noordberg.*

In November 2008 the number of coppice stools per hectare per site has been estimated between 1167 and 1591 and is slightly lower at the Noordberg than at the Laarsenberg (Tab. 1). In the most recently cut coppice site (Laarsenberg 1) the estimated number of sprouts per hectare reaches 8225, 8 growing seasons after the last harvest (in 2001) and no dead sprouts were detected. In the sites where the last cutting campaign took place between 22 and 32 years ago, less than 2000 living sprouts occur and many more dead stems were recorded (Tab. 1). The youngest, 8-year old, coppice sprouts of the Laarsenberg 1 site were on average 4.82 m high with an average diameter of 3.5 cm, while the oldest and highest stems (Laarsenberg 3) were 14.59 m in height and 16.6 cm in width (DBH). The average radial growth of the dominant stems in the coppice sites ranges from 2.08 mm (Laarsenberg 2) to 2.76 mm (Laarsenberg 3) and is not substantially different between both woodlands (Tab. 1). The average radial growth in the first formed 5 rings around the pith is slightly higher at the Laarsenberg sites, with 2.92 mm per year as the highest average ring width at the Laarsenberg 3 site (Tab. 1).

### *Is there a coppice fingerprint in ring-width patterns?*

In figure 3, average ring-width patterns are shown for the three Laarsenberg and two Noordberg coppice sites. The year-to-year (high frequency) variation in growth is similar both within as well as between woodlands. When the time series are aligned and plotted according to cambial age (Fig. 4) it becomes obvious that no consistency in growth trends exists within and between woodlands. There are sites showing a strong decrease in tree-ring width, either instantly after the first year (nb2) or after about 10 years (lb2) and there are sites with relatively stable growth (lb1 & lb3). When growth patterns of individual stems are taken into account, the variation even increases.

Although the first rings surrounding the pith are on average quite wide (Tab. 1, Fig. 2 & 3) hence reflecting vigorous juvenile growth, the pattern in ring width proved to be highly variable and therefore not applicable as a fingerprint of coppice management. Even when trees are grown under similar conditions with regard to soil type, stem and stool density as well as social status, the patterns in ring widths during the first five to ten years - but also the growth trend in the whole time series - fail to reflect a common specific pattern that could be linked to the coppice origin of the stems. The similarity in high-frequency variation between the ring-width series within and between the two woodlands (Fig. 3) suggests that environmental factors such as climate, have a major influence on the tree-ring pattern.

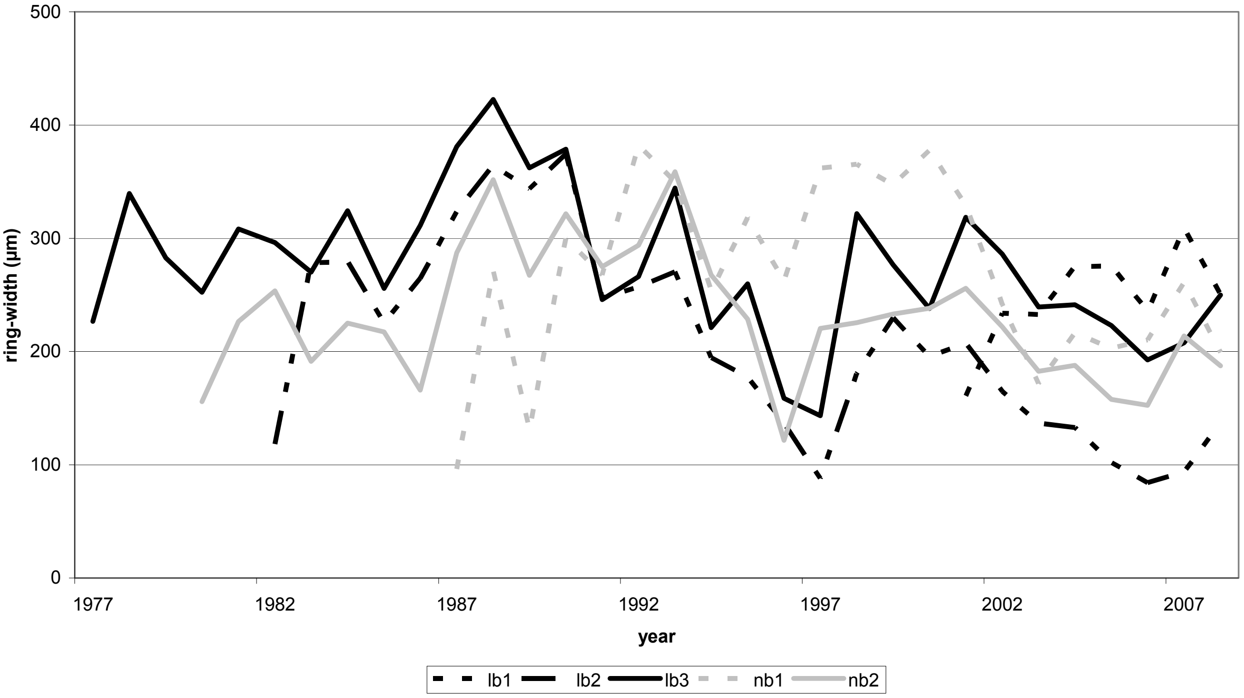

*Figure 3: Patterns of average ring width for the three Laarsenberg (lb) and two Noordberg (nb) sites.*

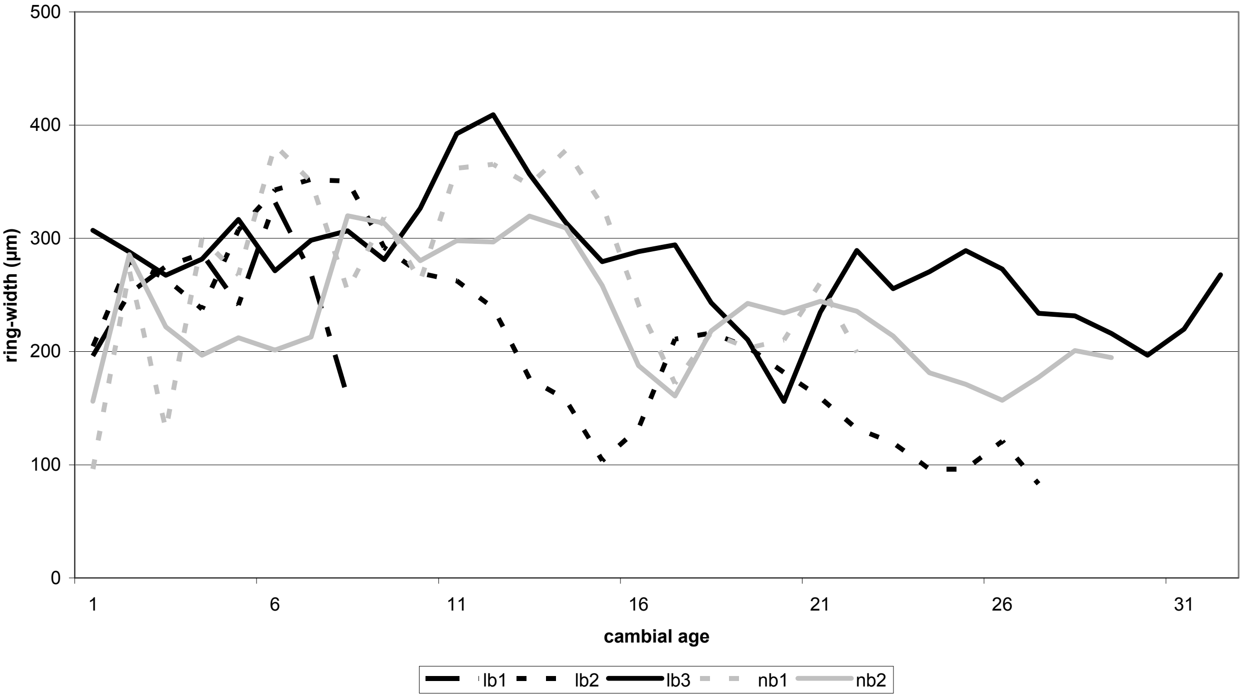

*Figure 4: Average ring width patterns computed according to cambial age: 1 is the first-formed ring around the pith.*

*Is there a coppice fingerprint in earlywood- width patterns?*

In comparison to ring width, EW-width patterns from all sites of both woodlands (Fig. 5) show less similarity in high-frequency when computed chronologically, both within as in between woodlands (Fig. 5). If the growth patterns are computed as cambial age (Fig. 6) a similar trend in EW width can be observed, independent of location during the first 10 years. After 10 years the similarity declines - the growth in the two Laarsenberg sites continues with the positive trend for another c. 5 years whereas growth in the two Noordberg sites stagnates. This consistency in EW-width trends over the first ten years could indicate a coppice-specific pattern. However, further research is needed to check whether seeded trees show a significantly different trend, taking into account amongst other things, social positions and soil types.

*Consequences for the reconstruction of woodland management using wooden artefacts.*

This study on contemporary oak coppice from two woodlands in the Netherlands indicates that there is a lot of variation in ring-width patterns of coppice shoots, even when only dominant stems, growing under similar conditions were considered. Although we found that rings formed around the pith are generally wide, we could not identify a consistent pattern as hypothesized by e.g. Haneca et al. (2005 & 2006) that can be taken as a fingerprint for wood originating from coppice.

Therefore, it is unlikely that ring-width patterns of wooded artefacts can be used to gain information on woodland management. In addition the use of growth patterns is even more complicated when the position of wood within the stem is considered. Only in the ontogenetically young rings - the rings formed just after germination or resprouting - information is stored regarding the origin of the stem. In wooden artefacts it is generally impossible to detect whether the first rings around the pith are the youngest, ontogenetically. Consequently it is not known whether wide rings around the pith are the result of coppice management or that they reflect vigorous growth of a seeded tree some years after germination.

A comparison of EW-width patterns in the oaks from the different coppice sites showed a similar pattern of increasing EW width during the first c. 10 years that might be used as a fingerprint of coppice management but first further research is needed to show whether this pattern is restricted to the coppice origin of the wood, or can be detected in seeded oaks as well.

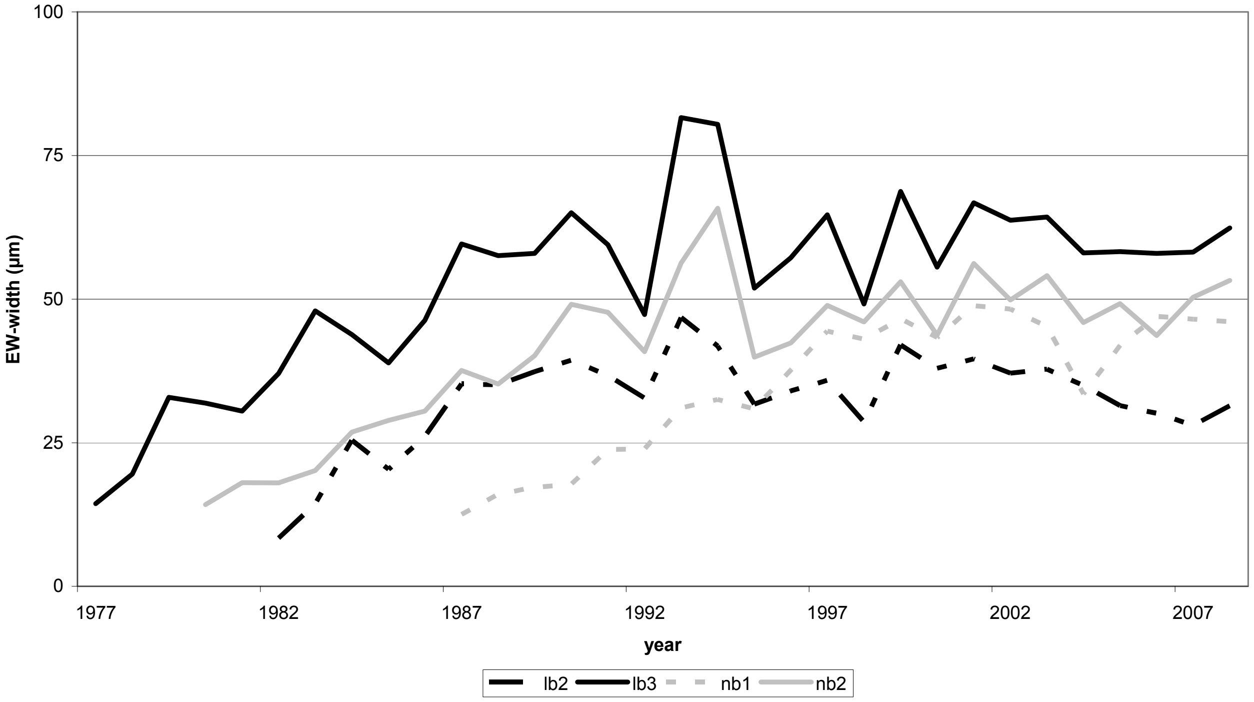

*Figure 5: Average EW width patterns for the sites Laarsenberg (lb) and Noordberg (nb).*

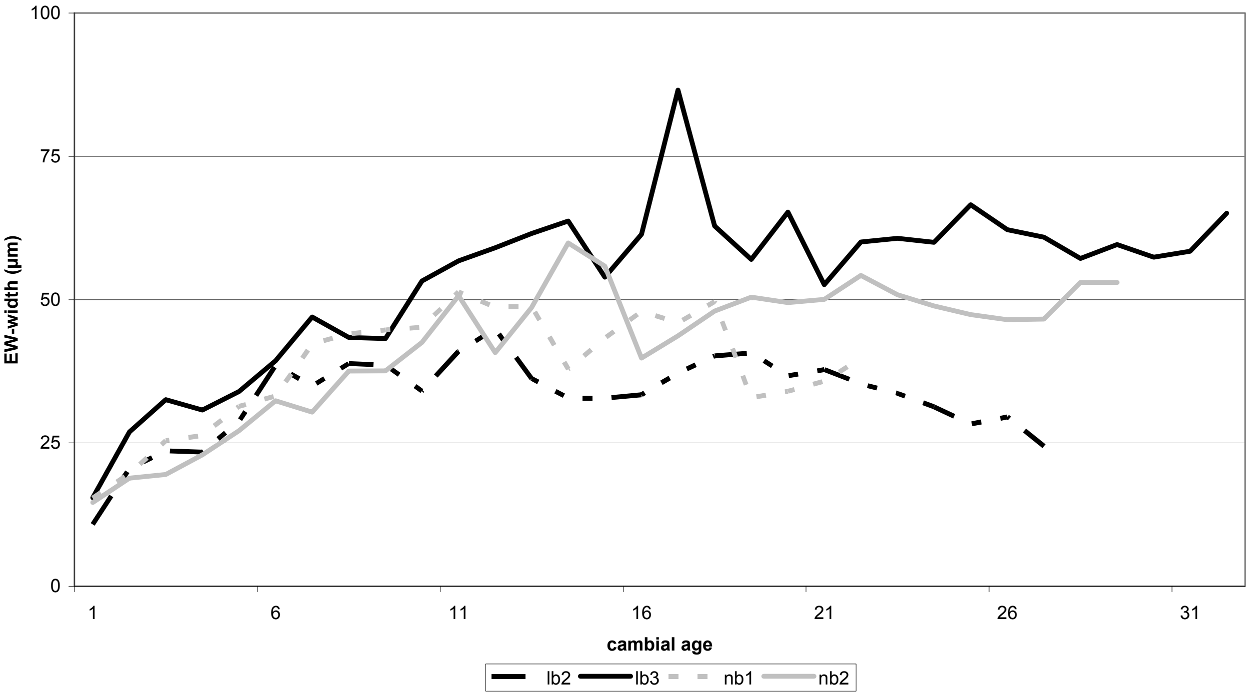

*Figure 6: Average EW width patterns computed as cambial age.*

### Conclusion and future perspectives

This study on contemporary oak coppice from two woodlands in the Netherlands indicates that the pattern of wide ring around the pith can not be used as a fingerprint of coppice management - it has been found that variation in ring widths around the pith is considerable, even in stems growing under similar conditions. EW-width patterns of trees from different coppice sites have found to be more consistent. However, further research is required to indicate whether this consistency in EW width is characteristic for oaks from coppice sites or can be found in seeded oaks as well. Further research is underway encompassing measurements on height growth, EW width and vessel-size patterns in coppiced stems as well as seeded trees.

### Acknowledgements

The authors wish to thank Wouter Bol and Leo Goudzwaard for their help in sampling and analysing. In addition we would like to thank the woodland managers Staatsbosbeheer (Noordberg) and Utrechts Landschap (Laarsenberg) for their help in site selection and for giving permission to sample trees.

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# SECTION 2

# CLIMATOLOGY

# Adaptability of forest species to climate change

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## Introduction

As part of the COFORD/Forest Research UK funded project CLIMADAPT, an assessment of growth across a climatic gradient (moist to dry) will be completed from western Ireland to eastern England. Constructing a sampling network of trees from forest stands growing on brown earth soils in Britain and Ireland would enable us to ascertain for any given tree-ring chronology, a discernible trend in response to climatic conditions. A pilot study has been initiated in Avoca forest, Co. Wicklow, on the east coast of the Republic of Ireland, to develop and test a methodology.

Tree ring analysis, height distribution, crown ratio, basal area and dbh were used to characterize tree growth and stand dynamics. Carbon and oxygen stable isotope values were measured around two recent drought events (1976 and 2003), covering the period from a year before to three years after each drought event.

The aim of this assessment was to understand and explain, using dendrochonological procedures and stand dynamics, tree adaptability to severe climatic conditions; especially moisture deficit and temperature. Using data from tree ring series and stable isotope analysis, meteorological records were analyzed to understand tree responses to adverse conditions. Their future adaptability to changes in our environment following IPCC scenario predictions will be modeled based on the results of this analysis.

The methodology developed in Avoca for Sitka spruce (*Picea sitchensis*) will later be extended to Douglas fir (*Pseudotsuga menziesii*) and Scots pine (*Pinus sylvestris*) growing on the same soil type across transects similar in accumulated temperature but varying in moisture deficit.

The study will contribute to a better understanding of the consequences of long-term climatic fluctuations; its expected outcome will inform advice on the implementation of better forest management practices and improve prediction of species suitability and adaptability to changing climatic conditions. This has future implications for species choice for afforestation and reforestation programs, as well as for timber supply forecasting.

## Data collection

Data for the pilot study were collected in six management plots of 20 x 20 m featuring three different thinning regimes of a 64 year old Sitka spruce stand: heavy thinning (HT) moderate/intermediate thinning (IT) and light thinning (LT). Sample trees were chosen from among the dominants in each plot because the growth of these individuals would have been least affected by the negative changes due to management and crown competitive status. A detrending method was applied to further remove disturbances caused by non-climatic factors (noise).

### *At stand level*

Meteorological data: moisture deficit (MD); accumulated temperature (AT) which is the sum of daily degrees day above 5 degree Celsius over the growing season (March to October), explained by the fact that 5°C is considered to be the threshold for photosynthetic activity (Grace et al, 2002); rainfall; and potential evapotranspiration (PET) were collected from the closest station, alongside tree diameter measured at breast height (dbh) for all trees in the plots, and the stand management (thinning history). The soil profile was described using the Ecological Site Classification methodology (ESC; Ray 2001). Two cores each were collected from five randomly selected dominant trees per plot.

*In the lab*

Cores were cross-dated, scanned and analysed with WinDendro Density™, to extract information on radial growth (cores_raw), tree ring maximum density (maxdens_raw) and blue reflectance (blue_raw).

A double detrending (a negative exponential followed by a cubic spline with 50% cutoff) was then applied on the data, using the Program ARSTAN XP (Cook and Holmes 1984).

Cores were shaved in 20µm slices with a sledge microtome, to collect earlywood and latewood portions of growth increment during A period of five years for each of the drought events selected (one year before, the drought year and the three following years). Cellulose was then extracted from the material collected, using an improved version of the procedure described by Brendel (2000), for carbon and oxygen isotope analysis by Kosi Lab in Gottingen, Germany. A pure cellulose sample was purchased from Sigma Aldrich to control the wood cellulose extraction process and spot any contamination from reagents in the lab.

The dataset used to prepare this paper does not include the complete results from the isotope determinations, as the analyses are still ongoing. However, isotope values from a limited number of cellulose samples (20) from a single tree were processed to adjust the cellulose extraction procedure and record the first trend of the tree's response to drought.

## Results

### *Site*

The soil was a brown earth, with a thin litter layer (0.5 cm). The A horizon was dark brown to mid brown (20 cm deep); with a silky-clay loam texture and a stoniness of about 5%. The rooting dept was about 70 cm and the humus type was Modder moll to Modder (Fig 1).

The above ground vegetation was essentially made up of broad buckler fern, fox glove, brackens, brambles, holly, bentgrass, chick weed, wood sorrel and hard ferns.

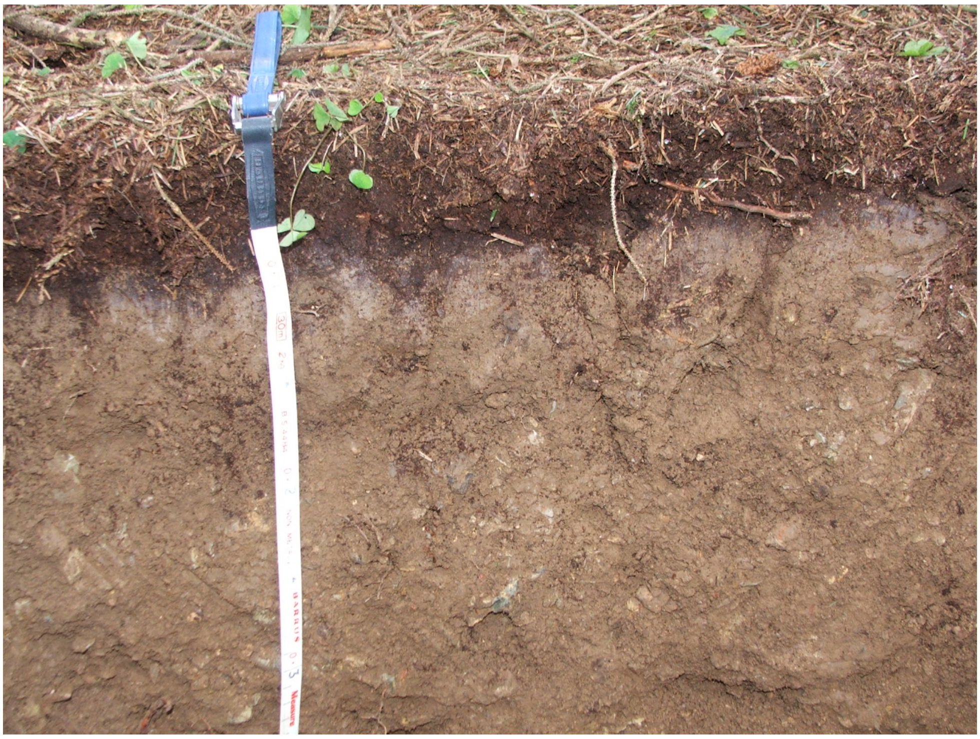

*Figure 1: Soil profile at Avoca.*

DOI: 10.2312/GFZ.b103-10058

### *Data*

14 variables were assessed to gather 22,893 data values to form the dataset which represents a chronology series extending from 1944 to 2008. Table 1 contains the mean, minimum and maximum values obtained for radial growth, blue intensity and maximum density raw and detrended data, together with temperature, moisture deficit and evaporation data for the site.

*Table1: Summary statistics of the dataset and highlights the distribution of the measurements.*

| Variable | Mean | N | Min | Max |
|---|---|---|---|---|
| Cores_raw | 3.656 | 1774 | 0.181 | 18.420 |
| Cores_ind1 | 1.006 | 1737 | 0.037 | 3.451 |
| Cores_ind2 | 0.987 | 1737 | 0.100 | 1.741 |
| Blue_raw | 357.300 | 1748 | 100.000 | 964.000 |
| Blue_ind1 | 1.000 | 1748 | 0.241 | 3.578 |
| Blue_ind2 | 0.998 | 1748 | 0.450 | 2.685 |
| Maxdens_raw | 189.700 | 1743 | 68.510 | 253.500 |
| Maxdens_ind1 | 1.003 | 1744 | 0.412 | 1.544 |
| Maxdens_ind2 | 0.997 | 1744 | 0.100 | 1.674 |
| AT_grow | 1997.000 | 1470 | 1654.000 | 2309.000 |
| Ann_MD | 137.700 | 1380 | 36.330 | 299.200 |
| MD_grow | 131.500 | 1410 | 36.330 | 299.200 |
| Rainfall | 3.740 | 1500 | 0.000 | 32.300 |
| PET | 0.460 | 1410 | 0.000 | 1.752 |

Abbreviations: Cores_: radial growth; Blue_: blue light reflectance; Maxdens_: maximum density; AT_: accumulated temperature; Ann_: annual; MD_: moisture deficit; PET: potential evapotranspiration; _raw: raw data; _ind1: first detrending; _ind2: second detrending; _grow: growing season;

### *Dendrochronology*

Express population signal for this pilot study was 0.99. The master chronology (Fig. 2) from raw radial increment showed a general declining trend which could be explained by tree and stand ageing. However, the sudden drop in tree growth in 1975 and 1996 could well be due to a stress that affected the trees.

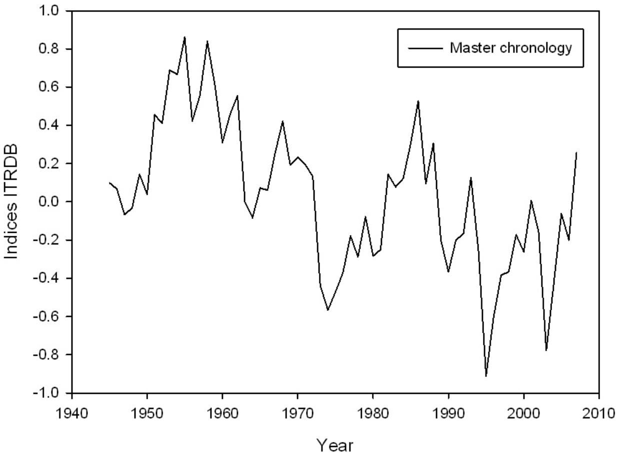

*Figure 2: Master Chronology Avoca, all plots.*

### *Climate*

Meteorological data at Glenealy (closest local met station) for the growing season (March – October) showed an increase of AT of about 250 degrees Celsius over the last 30 years (Fig. 3). Moisture deficit which was calculated as the excess evaporation over rainfall showed no significant increase over the same period, $R^2$=0.01 (Fig. 4). However, the severity of the stress in 1970 and 1992 led us to refine our method of selection of drought years for the study: instead of using the European drought years (1976 and 2003), local meteorological data will be used to identify periods of local drought, to better correlate moisture deficit with tree response. Whilst figures 3 and 4 show temperature and moisture deficit for the whole time series, our study will focus more on tree response to extreme climatic events, especially drought.

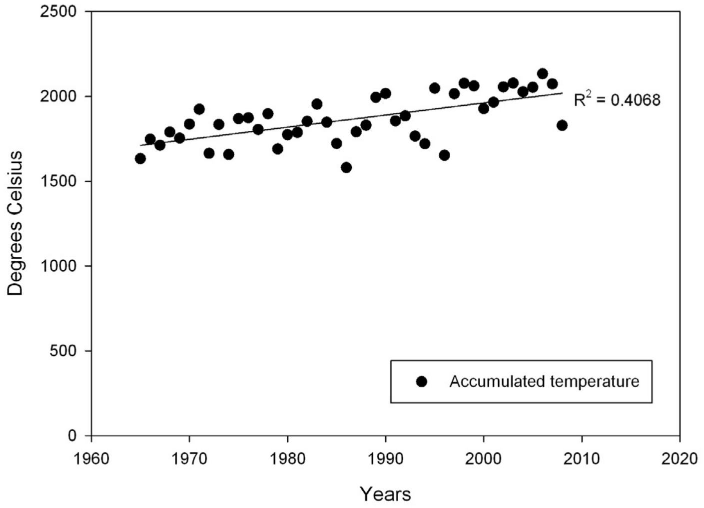

*Figure 3: Accumulated temperature at Glenealy between 1964 and 2008.*

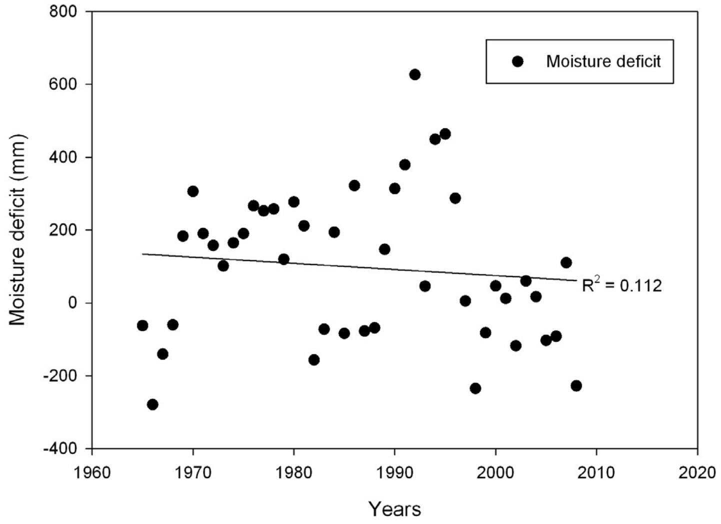

*Figure 4: Moisture Deficit at Glenealy (1965-2008).*

### *Blue reflectance*

Minimum blue intensity occurring in the latewood is thought to be well correlated with maximum density of the same wood portion and therefore, to be a good surrogate for past climate (Campbell 2007). The correlation matrix (Tab. 2) shows a significant relation between blue reflectance and maximum density, and blue reflectance and radial growth increment. The low correlations (0.084

and 0.112 respectively) indicate the need for further investigation and the use of advanced statistics to confirm this early result.

Earlywood period moisture deficit is negatively correlated to radial growth, blue reflectance and maximum density (Tab. 2), and the second detrending (data not shown) appeared to consistently reduce the strength of the correlation. This raises the question of the necessity for the second step of standardisation that we applied to the data. Further analyses are currently being done to resolve this question.

*Isotope values*

Results from cellulose extraction (data not shown) confirmed that the samples were reasonably contamination-free from chemical reagents

Analysis of carbon (C) and oxygen (O) isotope signals of extracted cellulose show discrimination of $\delta^{13}$Cc was 2 to 3‰ higher in late compared to early wood. Similar, but smaller differences (1 to 2‰) between early and late wood were also observed for $\delta^{18}$Oc signals. Differences in discrimination could be associated with a) a higher frequency of moisture deficits from July (Fig. 5), when late wood is being synthesized, and a corresponding increase in discrimination in response to the climatic signal; b) fractionation reactions downstream of C fixation or water recharge (see Helle & Schleser 2004, Barbour et al. 2002); or c) an increased fractionation of $^{18}$Oc and equilibration with ground source water following high rainfall events (Barbour et al. 2002; Tab. 3).

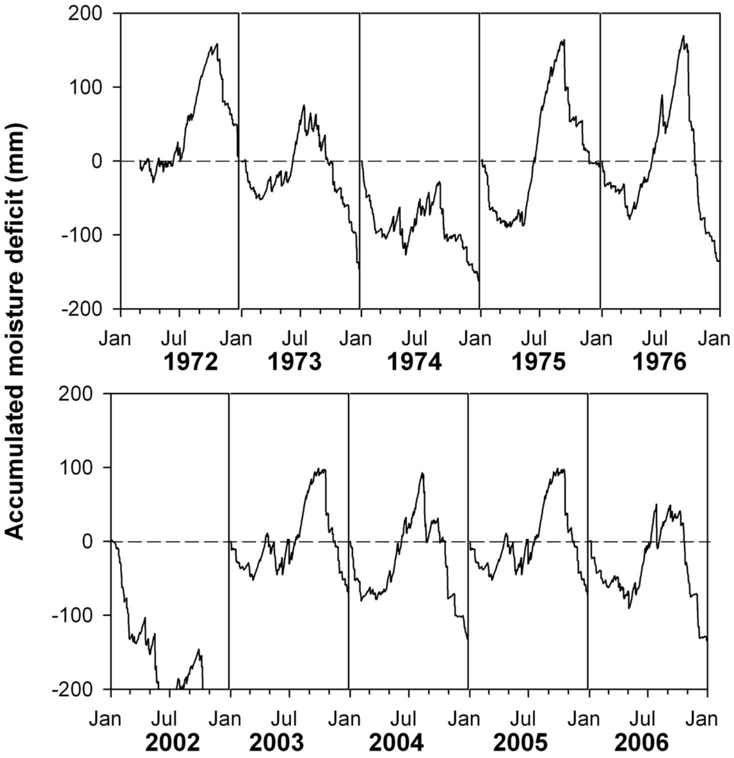

*Figure 5: The accumulated moisture deficit in years selected for isotope discrimination analysis. Note the high frequency of moisture deficits after June/July.*

*Table 2: Correlation matrix of raw and detrended data.*

| | Cores _ind1 | Blue _raw | Blue _ind1 | Maxdens _raw | Maxdens _ind1 | AT _grow | MD _grow | MD _EW | MD _LW |
|---|---|---|---|---|---|---|---|---|---|
| Cores_Raw | 0.459 | 0.0583 | 0.0747 | -0.0996 | 0.196 | -0.319 | -0.0832 | -0.158 | 0.0252 |
| P Value | 2.40E-91 | 0.0163 | 0.00207 | 0.0000325 | 1.79E-16 | 1.25E-32 | 0.00249 | 7.9E-09 | 0.361 |
| Cores_ind1 | | 0.0556 | 0.115 | 0.0739 | 0.151 | 0.00415 | -0.126 | -0.162 | -0.0308 |
| P Value | | 0.022 | 0.00000221 | 0.00205 | 2.37E-10 | 0.88 | 4.69E-06 | 3.45E-09 | 0.263 |
| Blue_raw | | | 0.708 | 0.307 | 0.303 | 0.152 | 0.0165 | -0.0285 | 0.0486 |
| P Value | | | 7.00E-266 | 1.33E-38 | 1.88E-37 | 3.17E-08 | 0.549 | 0.302 | 0.0776 |
| Blue_ind1 | | | | 0.19 | 0.386 | 0.184 | 0.0158 | -0.0377 | 0.0559 |
| P Value | | | | 2.67E-15 | 1.80E-61 | 1.77E-11 | 0.566 | 0.171 | 0.0425 |

(For abbreviations see Table 1).

Preliminary analysis suggests that late wood $^{18}$Oc showed the largest variation in isotopic fractionation (37.4 to 40.5 ‰), and that specific events, such as moisture deficits (MD) and high rainfall can be recorded in the $^{18}$Oc pattern, particularly for late wood samples (Tab. 3).

Based on autocorrelation between rainfall, PET and moisture deficit data, it is evident that the apparent significant discrimination of $^{18}$Oc under higher moisture deficits is a function of fractionation following rainfall events rather than PET. This could suggest that fractionation and equilibrium with the ground water $\delta^{18}$O signal may influence the overall $\delta^{18}$Oc signal. No apparent influence of leaf conductance (i.e. stomatal limitation) on the isotopic signal is consistent with lack of any correlation between $^{13}$Cc or $^{18}$Oc with PET or MD. However, the moisture deficit and vapour pressure deficit ranges in the selected sample years may be too low to elicit a stomatal limitation response and hence a corresponding $^{13}$C and $^{18}$O climatic signal. Current ecological site classification models suggest that Sitka spruce growth is only limited at moisture deficits above 200 mm (Ray et al. 2008), which is higher than the values observed in selected sample years. Additional isotope analysis on cellulose extract from years where there is a larger moisture deficit range (e.g. 1990 to 1996) is currently underway.

*Table 3: Pearson correlation coefficients with p-values (in parenthesis) showing the relationship between isotopic signals and climatic variables (n = 10). PET potential evaporation, MD moisture deficit, and mean T° represents the temperature in corresponding periods for late wood (LW) and early wood (EW) synthesis.*

| Isotope pattern | Climatic variables for corresponding period | | | |
|---|---|---|---|---|
| | **Rainfall** | **PET** | **MD** | **Mean T°** |
| $^{13}$Cc EW | -0.15 (0.67) | 0.39 (0.27) | 0.01 (0.97) | 0.31 (0.12) |
| $^{13}$Cc LW | -0.41 (0.22) | 0.19 (0.76) | 0.42 (0.22) | -0.07 (0.83) |
| $^{18}$Oc EW | 0.24 (0.49) | 0.07 (0.84) | -0.19 (0.54) | 0.51 (0.11) |
| $^{18}$Oc LW | -0.59 (0.04) | 0.17 (0.69) | 0.58 (0.05) | 0.05 (0.84) |

## Conclusions

A clear pattern of increase in accumulated temperature over the last three decades was observed; however, detailed analysis of data showed that local climatic stress explains tree response better than global stress occurrences in Europe. At this early stage of the study, dendrochronology and isotope analysis has shown a detectable response from trees; investigations are still ongoing to find out if this is linked to climatic stress. Blue intensity did elicit a significant correlation with

maximum density. These findings are still preliminary and more advance statistical analyses are being carried out to confirm the observed trends in the data.
The outcome of this pilot study will contribute to develop the methodology that will be implemented for all three species (Sitka spruce, Scots pine and Douglas fir) across the study transect.

## Acknowledgements

This study has been made possible through funding from COFORD (the National Council for Forest Research and Development in Ireland) and Forest Research UK. We gratefully acknowledge Eugene Sherry of the Plant Physiology Lab at UCD and Colin McEvoy of Forest Management Division at Forest Research UK, for providing the lab facilities and equipment necessary for the project.

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# Atmospheric Circulation indices derived from trees and GWL

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## Introduction

Large-scale atmospheric circulation patterns are the dominant drivers of weather conditions, which strongly influence tree growth. Central European circulation patterns can be classified into weather regime types, known as "Großwetterlagen" (GWL) (Hess & Brezowsky 1952, Gerstengarbe 2005).
The GWL data are nominally scaled and commonly used procedures for continuous time series analyses are unsuitable for investigating GWL influence on tree-ring growth. The only possibility is to work with GWL frequency distributions. Schultz et al. (2008) found no reasonable correlation, between tree-ring growth and GWL but discontinuous time series analysis showed a strong GWL influence on tree ring growth.
This paper presents a new approach for investigating the relation between tree-ring growth and GWL with continuous time series analysis using a Monte Carlo simulation. During the simulation, the GWL dataset is recoded and combined with tree-ring data. Based on this analysis, a set of new time series, called the "Atmospheric Circulation Tree-Ring Indices" (ACTI), are created. Two separate Monte Carlo simulations with different settings were applied with a test dataset consisting of 45 sites from a Central European North - South transect.

## GWL Basics

The GWL dataset has a daily resolution and covers the period from 1881 to the present. Each GWL persists for at least 3 days (Gerstengarbe 2005).
The 29 GWL can be grouped into 10 synoptic types and then into three circulation types: zonal, mixed, and meridional (see Tab. 1). The GWLs are related to air masses which have their own specific combination of properties in terms of humidity and temperature, etc. Every GWL has its own weather condition pattern, which is seasonally differentiated and modified by the topography and the changing paths of anticyclones and cyclones.

## Procedure for calculating ACTI

The procedure for calculating ACTI is mainly based on a Monte Carlo simulation. Therefore the results are computed by repeated random sampling in different runs. In each run a set of random numbers is used.
The procedure to calculate ACTI consists of four steps.
For each run the first step is to randomly assign weights to each GWL and then to replace all GWLs in the dataset with these randomly assigned weights for the calibration period. For each run, 29 random numbers, so-called GWL weights, which can have positive or negative values are used. From this re-coded dataset for different time periods, sums are calculated. The time periods can be defined by the user and can have for example annual, seasonal, monthly or weekly resolution. The sums are then transformed into absolute values.
The second step is to separate the re-coded GWL dataset into time series, the so-called GWL indices, which represent the different time spans. For example, when using a monthly resolution results in one time serie for each investigated month. In total there are 12 and with the previous year 24 time series and GWL indices, respectively.

*Table 1: GWLs and associated circulation types*

|  | No. | GWL abbreviation | GWL |  | No. | GWL abbreviation | GWL |
|---|---|---|---|---|---|---|---|
| zonal | 1 | WA | Anticyclonic Westerly | meridional | 16 | HB | High over the British Isles |
|  | 2 | WZ | Cyclonic Westerly |  | 17 | TRM | Trough over Central Europe |
|  | 3 | WS | South-Shifted Cyclonic Westerly |  | 18 | NEA | Anticyclonic North-Easterly |
|  | 4 | WW | Maritime Westerly (Block E. Europe) |  | 19 | NEZ | Cyclonic North-Easterly |
| mixed | 5 | SWA | Anticyclonic South-Westerly |  | 20 | HFA | Scandinavian High, Ridge C. Europe |
|  | 6 | SWZ | Cyclonic South-Westerly |  | 21 | HFZ | Scandinavian High, Trough C. Europe |
|  | 7 | NWA | Anticyclonic North-Westerly |  | 22 | HNFA | High Norway-Iceland, Ridge C. Eur. |
|  | 8 | NWZ | Cyclonic North-Westerly |  | 23 | HNFZ | High Norway-Iceland, Trough C. Eur. |
|  | 9 | HM | High over Central Europe |  | 24 | SEA | Anticyclonic South-Easterly |
|  | 10 | BM | Zonal Ridge across Central Europe |  | 25 | SEZ | Cyclonic South-Easterly |
|  | 11 | TM | Low over Central Europe |  | 26 | SA | Anticyclonic Southerly |
| meridional | 12 | NA | Anticyclonic Northerly |  | 27 | SZ | Cyclonic Southerly |
|  | 13 | NZ | Cyclonic Northerly |  | 28 | TB | Low over the British Isles |
|  | 14 | HNA | Icelandic High, Ridge C. Europe |  | 29 | TRW | Trough over Western Europe |
|  | 15 | HNZ | Icelandic High, Trough C. Europe |  | 30 | U | Undefined |

The third step is to calculate the Pearson's correlation coefficients r (Bahrenberg et al. 1999) between the tree ring data and the GWL indices. This procedure is repeated for all following runs. All results of the various runs are stored. The number of sites (ns), the number of runs (nr), and the number of investigated time spans (nts) define how many correlation coefficients and p-values are computed (ns*nr*nts). Due to the fact that the GWL is a large scale signal, a reasonable amount of sites are necessary to detect the signal properly. Furthermore, a large number of repetitions are necessary for a Monte Carlo Simulation. The combination of these two factors quickly leads to the situation needing greater computing capacity than is available from common software and computers.

The fourth step is to separate those runs for each site and period with the strongest correlation. So for the above described example 24 correlation coefficients would be extracted for each site. If all 24 GWL indices lead to significant correlations with respect to the multiple testing problem (see discussion) they are called ACTI.

The procedure for calculating ACTI does not depend on the number of sites, the investigated tree species, or the used tree-ring parameter like density, stable isotopes or tree-ring width. The overall procedure is always similar.

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### Test simulations

Two Monte Carlo simulations were carried out with R (R Development Core Team 2005) using the maximum available computer capability with different parameters (maximum 24 million correlation coefficients).

In total, 45 tree-ring sites from Germany, France, and Switzerland with a minimum of 12 dominant trees per site were used (Fig. 1). All tree-ring width series cover the time span between 1901 and 1990. The 45 sites are located along a transect from Germany's northwestern lowlands (100 m a.s.l.) to the high mountain regions of the Swiss Alps (2000 m a.s.l). The transect therefore represents a large ecological spectrum. Following tree species were investigated: *Fagus sylvatica (FASY), Quercus robur (QURO), Quercus petraea (QUPE), Pinus sylvestris (PISY), Picea abies (PCAB).* The transect is dominated by QURO. QUPE, and FASY. The raw tree-ring width series for each site were cross-dated with TSAPWin (Rinn 2005) and Cofecha (Holms 1983) and detrended by Arstan using a 32-year spline.

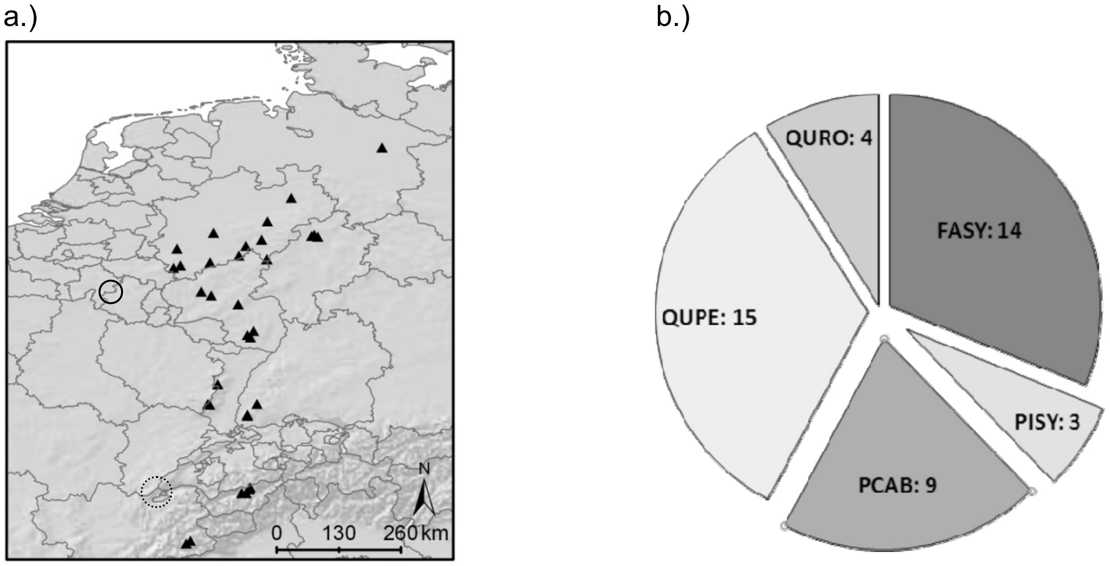

*Figure 1: a.) Spatial distribution of the tree-ring-sites. Not all sites are visible in the map, because of their short spatial distances to each other. One site in Rheinland-Pfalz and one site in the Lötschental is highlighted with a circle. b.) Frequency distribution of the tree species in absolute numbers*

The first simulation used 45 dendro-sites with 20,000 runs and the calibration period from 1931 to 1990. The second simulation, consisting of 10 dendro-sites with 100,000 runs and 45 randomly selected years between 1901 and 1990. In total 22 monthly time spans from January of the previous year to October of the current year, and two annual, the year and the previous year were investigated.

Figure 2 shows an example for the first simulation. The grey curve is the detrended site mean curve from a site from Reinland-Pfalz (see circle Fig.1), the black curve represents the corresponding ACTI for March. The stability of the correlation over time is checked (Fig.2) and it remains significant for the whole investigation period from 1901 to 1990, even outside of the calibration period. The two curves are positively correlated and show similar behaviour. The second example (Fig. 3) shows the ACTI for May from a high mountain site from the Swiss Alps (Fig. 1 dotted circle). The two curves are generally negatively correlated.

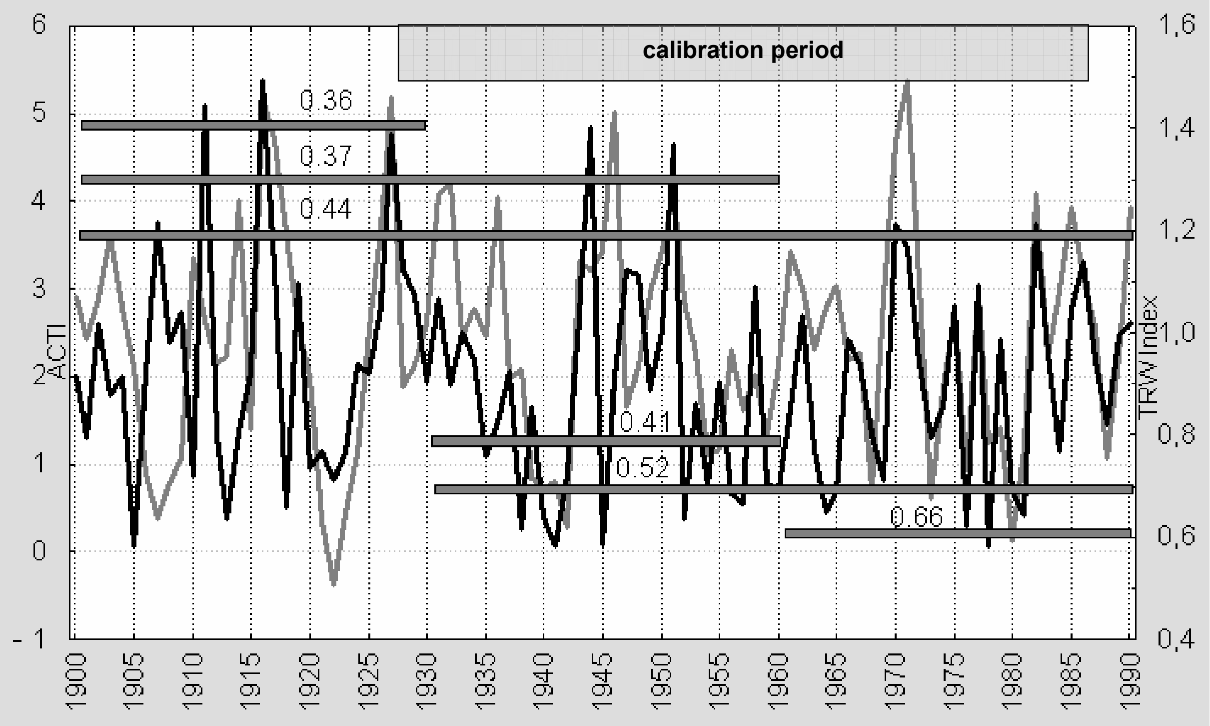

Figure 2: Comparison between the ACTI curve (black) for March and the detrended mean curve (grey) for the oak site located in Reinland-Pfalz (see Fig 1 circle). The grey bars indicate the correlation coefficient for different time periods. The calibration period is shown in the grey rectangle. The threshold for the 95% significance level is +- 0.34 for 30 years.

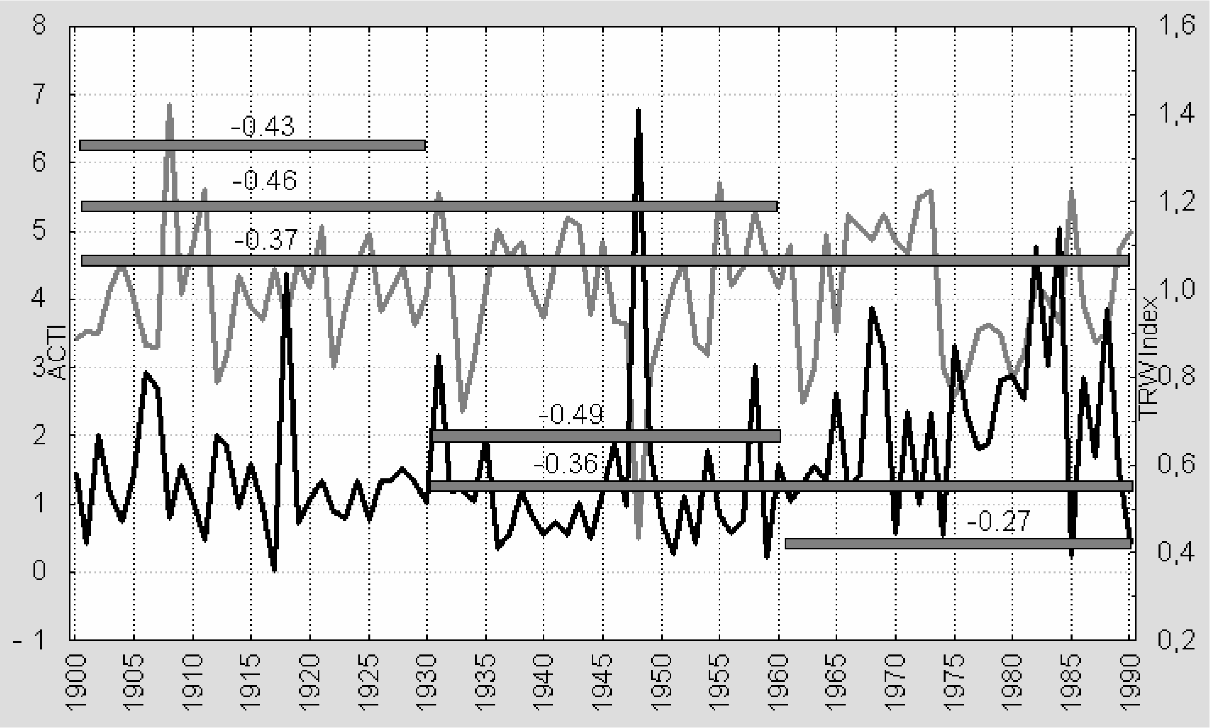

Figure 3: Comparison between the ACTI curve (black) for May and the detrended mean curve (grey) for a *spruce* site located in the Swiss Alps (see Fig 1 dotted circle). The grey bars indicate the correlation coefficient for different time periods. The calibration period is shown in the grey rectangle. The threshold for the 95% significant level is +- 0.34 for 30 years.

The correlation is not stable over time because all periods show significant correlations except the period from 1961 to 1990. Due to the fact that this ACTI is derived from the second simulation, no fixed calibration period was used. GWL is a large scale circulation pattern and we observed for both simulations that many sites and even different tree species correlated significantly with the same GWL weights.

It is therefore possible to group sites, based on the GWL weightings, and this is a good indication of the quality of the weights.

## Discussion and perspective

These initial results are encouraging and show that the ACTI seems to be a promising tool to examine the impact of large scale atmospheric circulation on tree ring growth. The influence of each GWL on tree-ring growth at a specific site can be estimated precisely, due to the GWL weights.

It is quite common to use a fixed calibration period, but the GWL data set is long enough to select random years for the calibration period. The advantages of randomly selected years are reduced influence of long term changes in the climate dataset, such as global warming, and reduced influence of auto- correlation. (Todman J.B., Dugard, P. 2001)

The main caveat of the ACTI method is Alpha inflation due to multiple testing. When several tests of significance are applied simultaneously, the probability of a type I error (rejecting a true null-hypothesis) becomes larger (Legendre 1998).

There are several ways to reduce this problem (Farcomeni 2008). The observed p-values in the two Monte Carlo simulations, especially in the second simulation, are mostly low enough to be considered significant after adjusting the Alpha level. Furthermore, the site grouping leads to more reliable results because the probability of type I error is reduced.

By applying this method, following questions can be addressed:

- Is the spatial pattern of tree-ring growth in Central Europe explainable by ACTI?
- How intense is the impact of GWL on tree ring growth?
- Does the sensitivity of different tree species toward GWL vary?
- Are the lowlands as sensitive as the high mountain regions with regard to the GWL influence?
- Is an altitudinal gradient, a north south, or west east gradient in the investigation area observable?

The next step consists of including more sites in the investigation and increasinge the number of repetitions. Due to limited computing capacity, the need to adjust the Alpha level and the grouping of the dendro-sites, a C program is in development. After grouping the sites and adjusting the Alpha level, a high resolution GWL reconstruction is enabled by reconstructing ACTI and comparing the groups. This method appears a promising procedure for understanding and reconstructing past weather conditions.

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# Exploring the potential of *Pinus heldreichii* CHRIST for long-term climate reconstruction in Albania

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## Introduction

Recent global warming and its potential impact on the hydrological cycle and subsequent ecological implications strengthens the need to quantify the degree of past natural climate variability. This demand becomes even more critical particularly for drought sensitive though, densely highly populated regions with intense agricultural background, such as most of the Mediterranean basin. Although significant progress has been made in assessing past climate variations over Europe, most long-term high-resolution reconstructions are restricted to temperature variations at high latitudes or altitudes. The Balkan Peninsula plays a key role as climatic transition zone between the west and eastern Mediterranean and also between the Mediterranean and Central European synoptics (Griffiths et al. 2004, Xoplaki et al. 2003, Xoplaki et al. 2004, Nicault et al. 2008, Qiriazi & Sala 2000). It is, however, still in an early stage of development from a dendroclimatological perspective (Vakarelov et al. 2001, Panayotov et al. 2009 a, b, Büntgen et al. 2007, Popa & Kern 2009).

Albania appears as a pure white spot in terms of existing tree-ring studies but provides large areas of *Pinus heldreichii* CHRIST forests, an endemic, long-living high-elevation species on the Balkan Peninsula and southern Italy.

Here we present new millennium-long tree-ring width (TRW) and maximum latewood density (MXD) records of various *Pinus heldreichii* sites across Albania*.* We explore local- to regional-scale signal strength of the different chronologies, and evaluate parameter-specific climate sensitivity with particular emphasize on potential age-related changes in climate response. Our results are discussed in the light of potential long-term climate reconstruction.

## Data and methods

Three ecologically different high-elevation sites along a north-south gradient in Thethi (AT), Lura (AL) and the Cuka Partisan in the Tomorri massive (AP) were sampled (Fig. 1, Tab. 1). The most northern region Thethi is located in the Dinaric Mountains on limestone bedrock. Three sites were sampled on a south/east exposed slope at different altitudes (AT1 1700 m, AT2 1900 and AT 3 1800-1900 m a.s.l). In the adjacent Albanian Mountains the Lura site (National Park since 1966) is characterized by basic metamorphic bedrock. Samples at AL1 were taken around a small lake in 1800 m a.s.l., while AL2 is situated on a steep south/west exposed slope close to the local tree line in 2000 m a.s.l. The Cuka Partisan is the most southern region where samples were taken in 1800-2000 m a.s.l. in stands on Leptic regosols above limestone bedrock. AP1 and AP2 differ in their ecological conditions in the sense that AP2 is located on a very shallow, dry steep rocky slope. Particularly, at Thethi and Lura also dry dead wood remains display an important source to extend living chronologies back into medieval times.

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Two cores per tree (living and dead wood) were sampled with a 5 mm diameter increment borer. Furthermore, samples from dead wood were taken as stem disks. TRW was measured by separating early and late wood width. MXD was measured for a subset of 7 cores (4 series from AT, 3 series from AL), which cover the period 1796-2006.

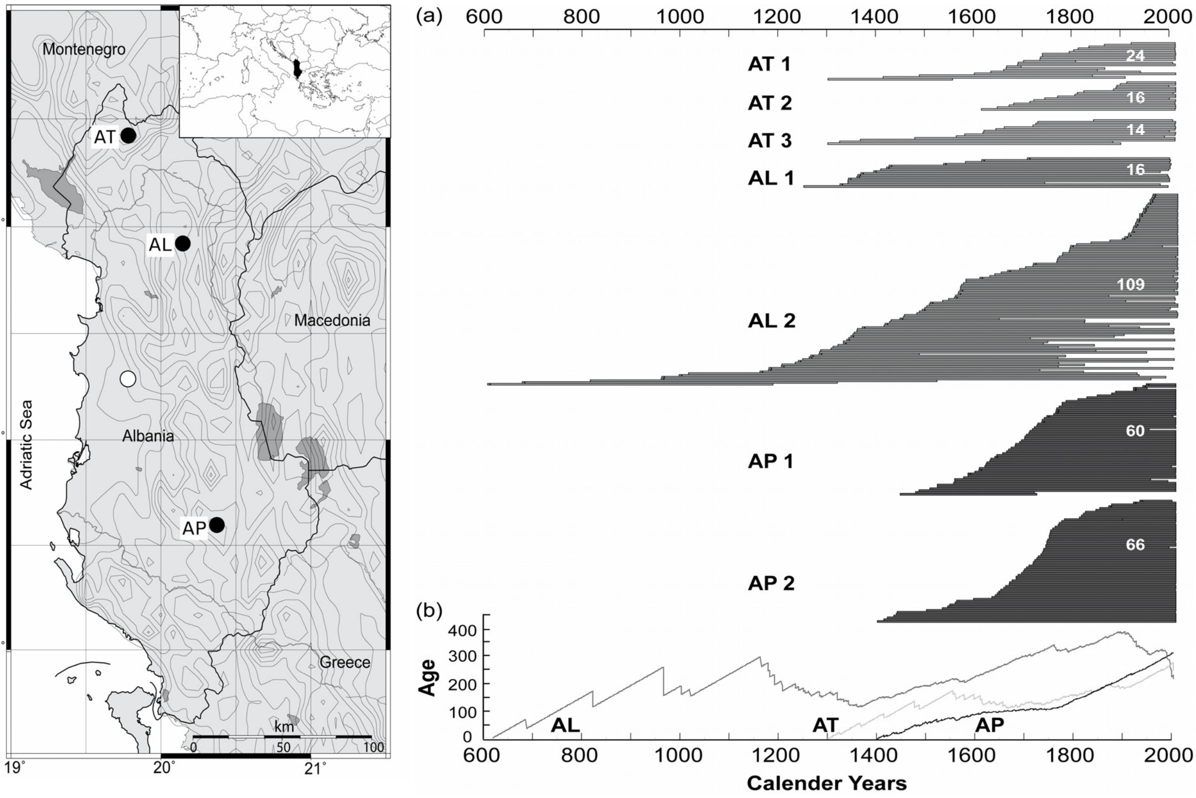

*Figure 1: a) Location of the sampling sites (black circles) and instrumental station data of Tirana (white circle); b) Replication and mean cambial age of the three sampling sites, with each bar representing one individual series.*

Maximum and mean segment lengths (MSL) of the series are 638 and 277 years for AT, and 604 and 308 years for AP (Tab. 1).

The highest replication is 99 trees and 124 radii (AL), including dead and living wood (Fig. 2). This site also provides the oldest material (mean segment length 397 years), with one dead individual counting even 1017 tree rings.

For all samples were the pith couldn't be reached because of sizable tree diameter, the number of missing innermost rings (pith offset, POE) was estimated. This procedure allows a more accurate application of regional curve standardization (RCS, Esper et al. 2003). The average POE ranges from 41 years at AP to 118 years at AT (Tab. 1).

According to standard procedures, tree-ring width (TRW), but also early (EWW) and late wood width (LWW) measurements were performed. Resulting series were cross-dated and any dating errors corrected before removing non-climatic, tree-age related growth trends (Fritts 1976). Based on RCS detrending we developed 7 site chronologies, 3 regional chronologies (AT, AL, AP) and one master chronology (ALB). Moreover, three chronologies based on different age classes (<300 years, 300-500 years and >500 years) were developed using the full data set to test if climate signals are age dependent. All resulting records capture inter-annual to centennial scale information and were subsequently compared with regional instrumental records.

*Table 1: Main characteristics of the site and regional chronologies combined in the Albania data set. Listing of the location, number of trees and radii, covered time span, mean segment length and mean interseries correlations of the raw and RCS-detrended Rbar-values.*

| **Code** | **Elev. (m a.s.l.)** | **Trees (n)** TRW/ *LWW* | **Radii (n)** TRW/ *LWW* | **Period (truncation > 5 series)** | **MSL** | **Rbar (TRW)** | **Rbar (LWW)** | **mean Rbar -raw- (TRW)** | **mean Rbar (TRW)** | **mean Rbar (LWW)** |
|---|---|---|---|---|---|---|---|---|---|---|
| **AT** | **1700 - 1900** | **41/ -** | **54/ -** | **1303 (1479) - 2007** | **277** | **0.53** | - | 0.17 | 0.16 | - |
| AT 1 | 1700 | 18/ - | 24/ - | 1306 (1660) - 2007 (2006) | 236 | 0.453 | - | 0.12 | 0.15 | - |
| AT 2 | 1900 | 12/ - | 16/ - | 1614 (1720) - 2007 | 228 | 0.558 | - | 0.25 | 0.22 | - |
| AT 3 | 1800 - 1900 | 11/ - | 14/ - | 1303 (1580) - 2007 (2006) | 404 | 0.578 | - | 0.27 | 0.18 | - |
| **AL** | **1800 - 2000** | **99/ *92*** | **124/ *113*** | **617 (1003) - 2008** | **397** | **0.523** | **0.284** | 0.22 | 0.14 | 0.11 |
| AL 1 | 1800 | 16/ *16* | 16/ *16* | 1257 (1374) - 1997 | 546 | 0.498 | 0.157 | 0.12 | 0.27 | 0.05 |
| AL 2 | 2000 | 82/ *76* | 108/ *97* | 617 (1003) - 2008 | 375 | 0.548 | 0.32 | 0.21 | 0.17 | 0.14 |
| **AP** | **1800 - 2000** | **79/ *79*** | **126/ *126*** | **1405 (1445) - 2008** | **308** | **0.564** | **0.342** | 0.24 | 0.21 | 0.16 |
| AP 1 | 1800 - 2000 | 39/ *39* | 60/ *60* | 1451 (1526) - 2008 | 302 | 0.567 | 0.339 | 0.19 | 0.16 | 0.13 |
| AP 2 | 1800 - 2000 | 40/ *40* | 66/ *66* | 1405 (1445) - 2008 | 313 | 0.584 | 0.358 | 0.31 | 0.26 | 0.18 |

For analysing the growth/climate response, instrumental temperature (1951-1981) and precipitation (1951-1990) data of Tirana (89 m a.s.l., 41° 18'N, 19° 48'E), were used covering the period 1951-1981 for temperature and 1951-1990 for precipitation. Due to the shortness of the local measurements, longer instrumental station data from Thessaloniki in Greece (115 m a.s.l., 40° 39'N, 22° 58'E) were applied. Mean annual temperatures between Tirana and Thessaloniki correlate by 0.75 ($p<0.01$) for the common period of 1951-1981, precipitation data, however, do not appropriately represent local conditions ($r=0.38$, $p<0.05$). Additional calibration tests using meteorological grid data of 0.5° resolution (CRU TS 2.1; Mitchell & Jones 2005) did not provide convincing results.

## Results

### *Site chronologies*

The strength of the common signal within the local and regional data sets is indicated by the mean inter-series correlation (Rbar) (Tab. 1) and the „Expressed Population Signal“ (EPS) (Fig. 2). Values reaching the threshold of 0.85 indicate that the chronology appropriately represents the population growth at the site (Wigley et al. 1984). Robust EPS and Rbar statistics reach back to 1585 AD at AT, to 1295 at AL, and to 1535 at AP. The LWW records are generally more heterogeneous, but contain a robust common signal as well at AL from 1370 AD and at AP from 1635 AD on.

RCS-detrended site chronologies (TRW) at Thethi correlate between AT1 and AT2 with $r=0.45$, between AT2 and AT3 with $r=0.50$ and between AT1 and AT3 with $r=0.41$, at Lura between AL1 and AL2 with $r=0.41$ and at Cuka Partisan between AP1 and AP2 with $r=0.58$ (all: $p<0.01$; common period 1405-1997). The correlations between regional chronologies vary but in all cases are highly significant ($p<0.01$). Highest relationships are found between regions close to each other, with AT-AL $r=0.61$, AL-AP $r=0.67$ and between AT and AP $r=0.38$ (common period 1405-2007), mirroring nicely the north-south gradient. Interestingly the Thethi region shows a different long-term behaviour in the late 20th century with a decreasing instead of an increasing trend. Although RCS-detrended LWW chronologies weakly correlate between sites, regional chronologies of AP and AL are highly correlated with r=0.65 (p<0.01; common period 1405-1997).

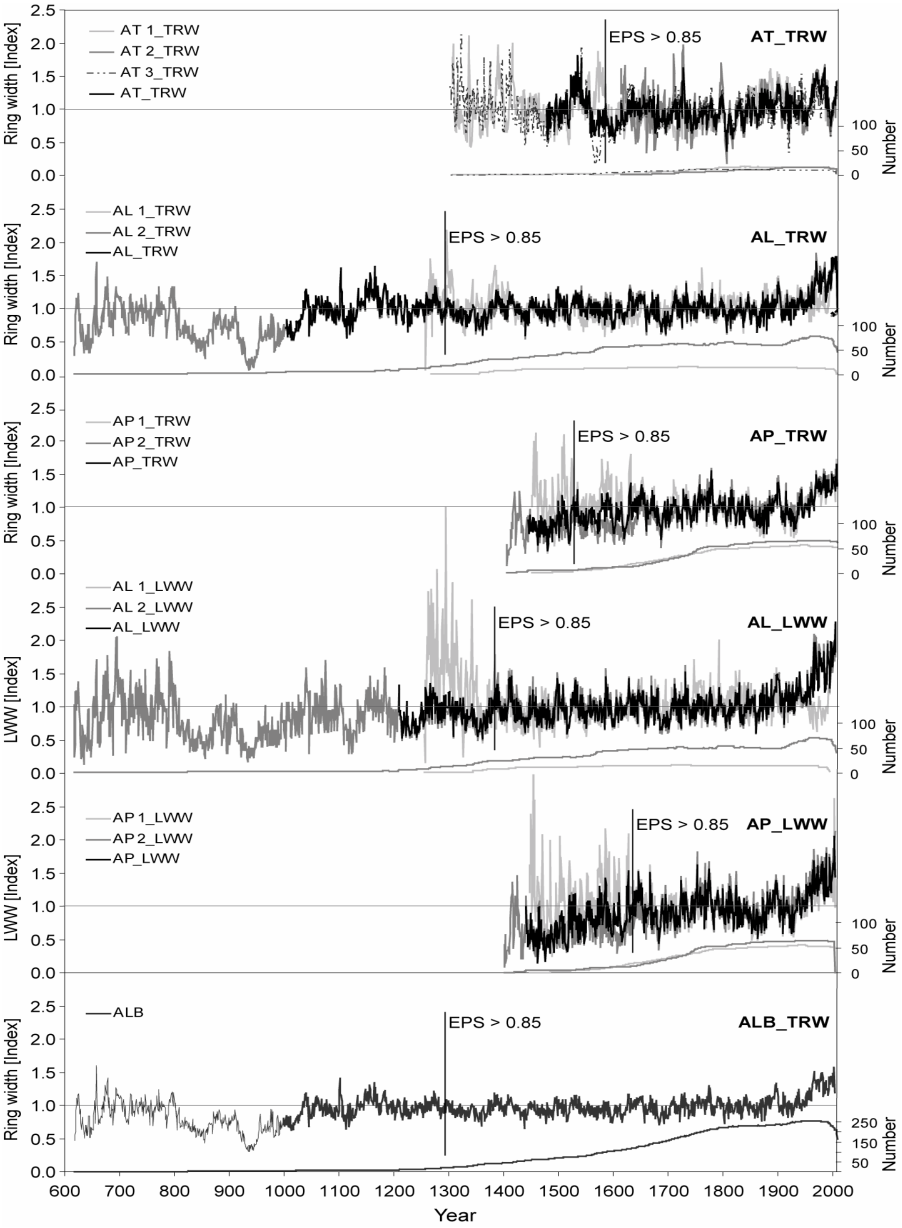

*Figure 2: RCS-detrended TRW and LWW chronologies separated by sites after standardisation over their full lengths. At the bottom all regional TRW-chronologies combined to a master chronology. In black the regional chronologies and the master chronology (ALB) after truncation <5 series. Vertical lines indicate the dates where the EPS is robust above the 0.85 threshold.*

Since both chronologies at Lura (AL1 and AL2) are composed of different age classes with AL2 containing many young and AL1 only old trees, it becomes obvious, that the influence of younger trees plays an important role in preserving longer-term trends (Fig. 2). We investigated this finding by splitting the complete data set (ALB, Albania) into age classes of young (<300 years), middle (300-500 years) and old (>500 years) tree rings. At the same time, we ensured evenly replicated subsets. Resulting age classes reflect different growth trends: the young trees grow faster by ~2 mm than the middle and old trees with just 1.5 mm (Fig. 3a).

Deviations in long-term trends of RCS-detrended age-class chronologies until 1850 are obviously caused by declining replication of young trees in this period (Fig. 3b). After 1950 the <500 age class remains on a persistent growth level while the young age class shows a slightly increasing trend. Decadal scale patterns of all age classes, however, are rather similar, particularly between 1900 and 1960.

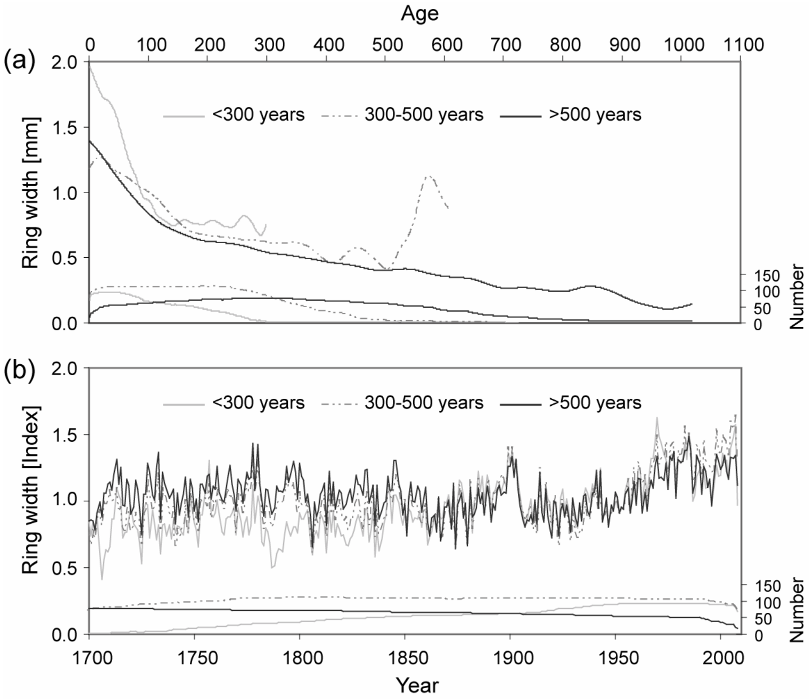

*Figure 3: (a) Mean growth trend in the three age classes (b) RCS-detrended age-class chronologies for the last 300 years. At the bottom of the panels the sample replication is shown.*

### *Climate response*

Correlations of regional (AT, AL and AP), age-class and MXD chronologies against local instrumental temperature and precipitation data of Tirana (1951-1981 and 1951-1990) were computed using a 24-month window from previous year January to current year December, along with various seasonal means and sums, respectively (Fig. 4). Besides positive correlations with temperatures and negative correlations with precipitation of previous May, summer (June/July) temperatures of the current as well as the previous year correlate negatively to TRW of high mountain pine at our sites (Fig. 5, left). The negative influence of high temperatures on tree growth is interpreted as indirect drought signal. AT reacts most strongly to previous and current July, a signal that is slightly weaker recorded in the latewood width especially of the southern region AP, and also in the different age classes (Fig. 5, right). Taking also positive (although weak) precipitation correlations into account, it seems, however, that younger tree-rings (<300 years) react more sensitive to drought conditions particularly in the driest months July and August. Consequently, the climate information contained could be related to climate-signal age-effects, as reported earlier (Esper et al. 2008). In contrast MXD yields, with care of the very low replication, high positive correlations to summer, particularly August temperatures ($p<0.05$) and no significant correlation to precipitation. This finding is promising but needs to be confirmed by more proxy and better target data.

It has to be noted, however, that all relationships are represented by a short 31-year common proxy/target period only. When replacing local temperature data of rather limited length with century-long instrumental measurements of Thessaloniki for the same period, most of the significant correlations stay robust (not shown). Extending the time window to the full period (1900-2008), however, refutes any significant relationships except for Thethi, where negative correlations to summer temperature remain and only decrease from $p<0.01$ to $p<0.05$. Figure 5 shows that the correlation between TRW (<300-year age class) and summer temperatures is associated with a temperature decrease to coolest and also moist conditions (not shown) of the 20th century. This increase of the negative influence of summer temperatures is also confirmed by moving correlation. The positive MXD-temperature relationship seems to be mainly related to the high frequency, is robust until the 80ths and brakes down afterwards.

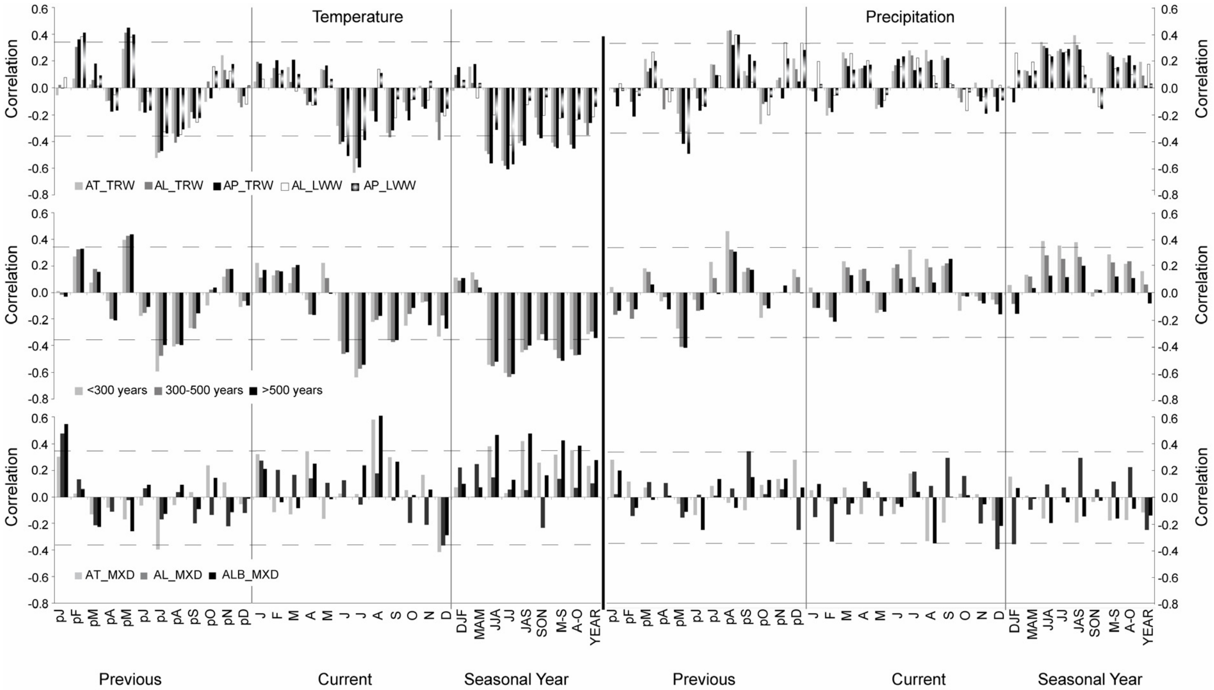

*Figure 4: Growth/climate response of TRW, LWW, age classes and MXD using temperature (1951-1981) and precipitation data (1951-1990) of Tirana for the period 1951-1981. Horizontal dashed lines represent the 95% significance level.*

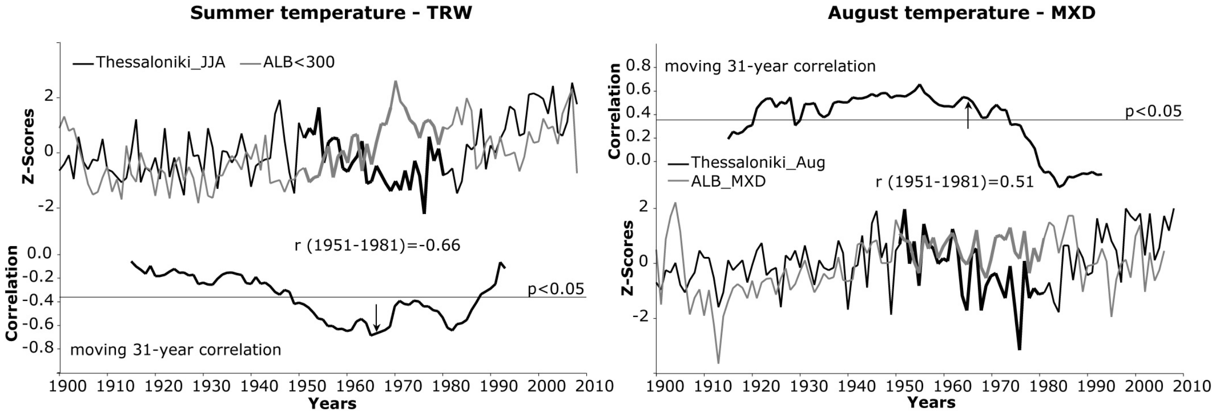

*Figure 5: Correlation of TRW and MXD with instrumental station data of Thessaloniki (Greece) and moving correlations in 31-year time windows; Left: <300 years age-class TRW chronology and JJA temperatures, right: initial MXD chronology and August temperatures. Arrows indicate the correlation obtained with instrumental data of Tirana.*

## Discussion and Conclusions

We developed a 1391-year long tree-ring width chronology including living and dead *Pinus heldreichii* CHRIST trees from Albania (617-2008 AD). Robust Rbar and EPS statistics are recorded back to 1250 AD. Regional records were separately correlated with the instrumental station data from Tirana and Thessaloniki. Climate correlation tests of RCS-detrended TRW and LWW records with local data show a negative response to June-July mean temperatures (common period 1951-1981) and a positive, but lower response to the precipitation amount at the same time.

The high common signal observed both within and between Albanian regions and similarities of our Albanian master chronology with other high elevation *Pinus heldreichii* chronologies from Bulgaria (Panayotov et al. 2009), Greece (Kuniholm & Striker 1987) and Italy (Serre-Bachet 1985) indicates that this species captures a common signal over a broader area.

Climate growth relationships were performed with data partly far away from our sampling sites. Negative correlations to temperature have to be interpreted as indirect indicator for drought sensitivity. Low correlations with local precipitation data may indicate that these records still do not appropriately represent local site conditions and, hence, need to be interpreted with care. Panayotov et al. (2009) also observed a similar relationship of the radial growth pattern of *Pinus heldreichii* in the Pirin Mountains (Bulgaria) to high temperatures and low precipitation in summer under similar site conditions on soils with a low storage capacity of water during dry months.

Analyses of various age classes indicate that younger trees contain more distinct variations than old tree-rings (>500 years). Taking also positive (although weak) precipitation correlations into account, it seems that younger trees (<300 years), react more sensitive to drought conditions particularly in the driest months July and August maybe due to shallow root systems. Our first tests with drought indices such as PDSI (van der Schrier et al. 2006), however, did not yield convincing results. Additionally, it needs to be considered that despite sampling was performed at the highest forested elevations the thermal tree line in the study area would be about 500m higher. In combination with an extended vegetation period, this results in less defined growth controls (Körner 1998).

In conclusion, tree ring chronologies of Albanian high elevation *Pinus heldreichii* contain a strong common signal and potential to cover at least the last millennium, although the climatic signal is still too weak for robust reconstruction. We hypothesize that (a) the instrumental data currently used are not yet appropriate enough to clearly identify the signal recorded and that (b) our sites might not be "extreme" enough to be continuously controlled by one meteorological variable only. MXD data seems to be a useful complementary parameter for "pure" temperature information, as reported for other relatively dry western Mediterranean sites (Büntgen et al. 2008). To substantiate the strength of the signal, however, more extensive measurements of MXD are required to raise the replication.

Future efforts will focus on (i) additional material to increase sample replication before 1250 AD, (ii) dead wood, historical timbers and sacral icons, (iii) low-elevation *Pinus nigra* sites, (iv) longer and better homogenized instrumental data (v) stable isotope measurements to enhance the drought signal (Treydte et al. 2007) and (vi) local- to regional-scale drought reconstructions

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# Climate reaction of old stands *Pinus sylvestris* L. in Gołąbki Forest Inspectorate (Poland)

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## Introduction

A stand of Pinus sylvestris L. in Gołąbki Forest Inspectorate (GFI) is one of the oldest natural conifer stands in Northern Poland. Because of forest management, natural forests in Poland are dominated by Scots pine. Old stands have very non-specific reaction on changing weather conditions, because of loss of the climatic signal during the ageing process. Sometimes the same factors caused different reaction within trees population (as in the GFI), Moreover strong influence of human management (deforestation, agriculture, increasing air pollution) causes greater sensitivity of trees, especially old ones for environmental stresses.

## Study area and its climate

GFI is situated in the middle part of Great Poland Lowland on Gnieźnieński Lake District (Fig. 1). This is postglacial region with mean height about 95-100 m above sea level. The landscape is dominated by arable land.

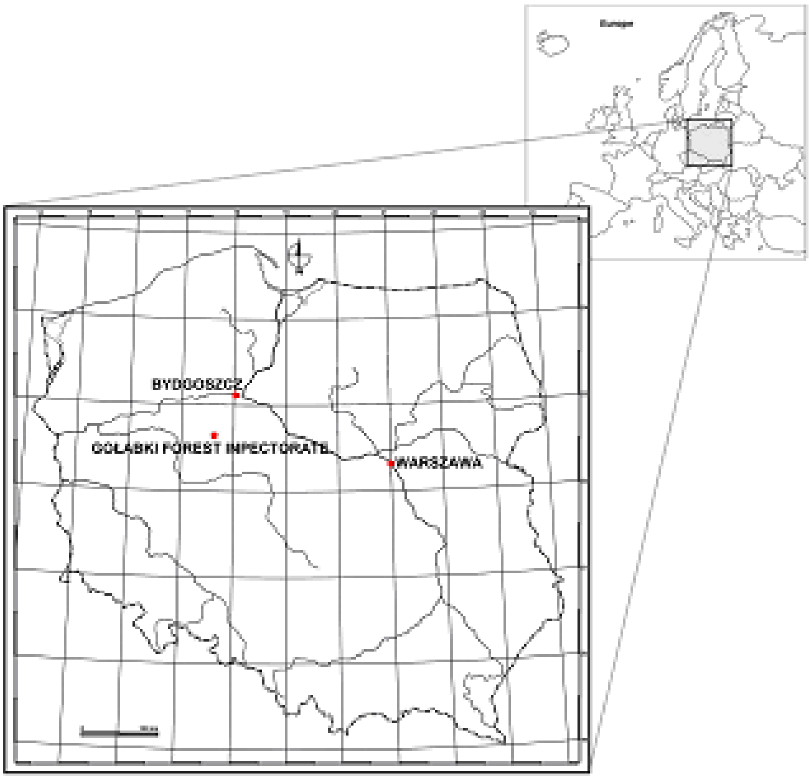


*Figure 1: Site location and meteorological station in Bydgoszcz.*

The study area is characterized with moderate transitory climate. Typical for this type of climate is great variability of weather and climate conditions. GFI is located at a rather warm site. Mean annual air temperature during the 1951–1980 period was 7.8ºC. Maximum values in annual course of air temperatures are reached in July (17.9°C) (Fig. 2). Minimum values occur during January (-2.5ºC). These climatic conditions, result in a vegetative season of approximately 220 days (since the end of the March to the beginning of the November).

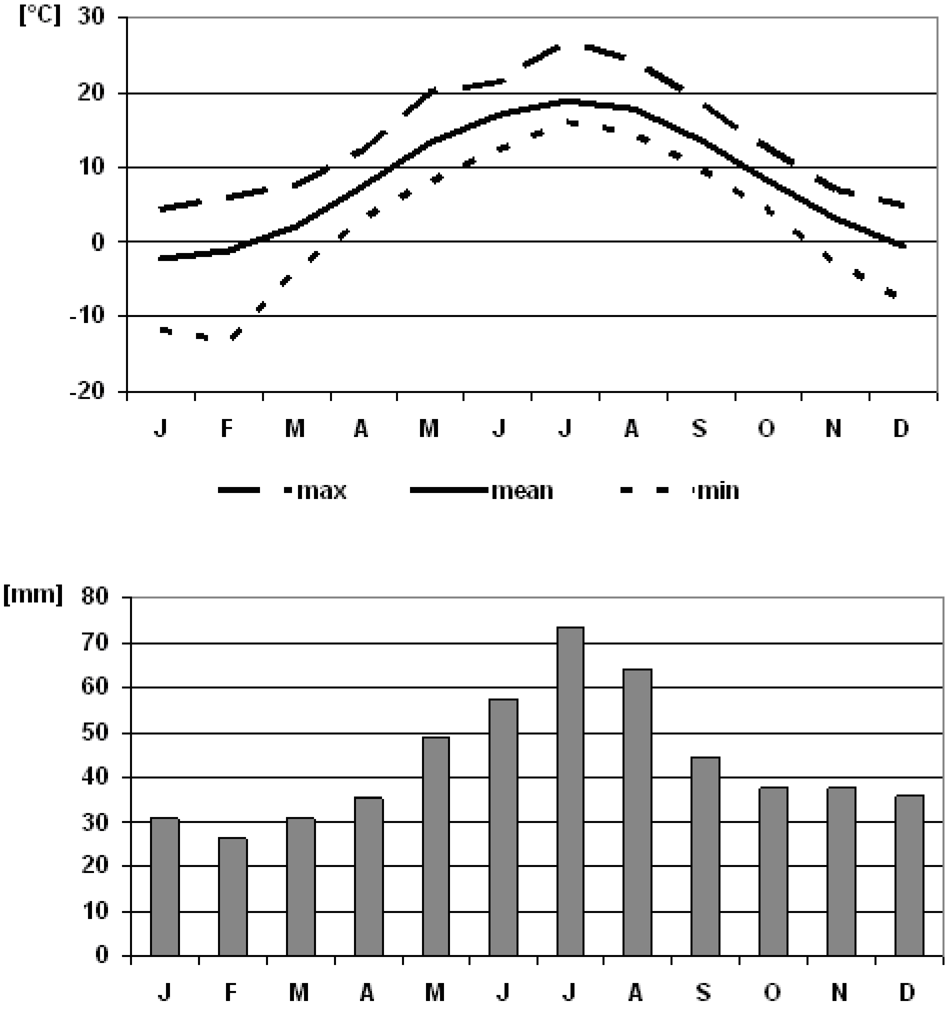
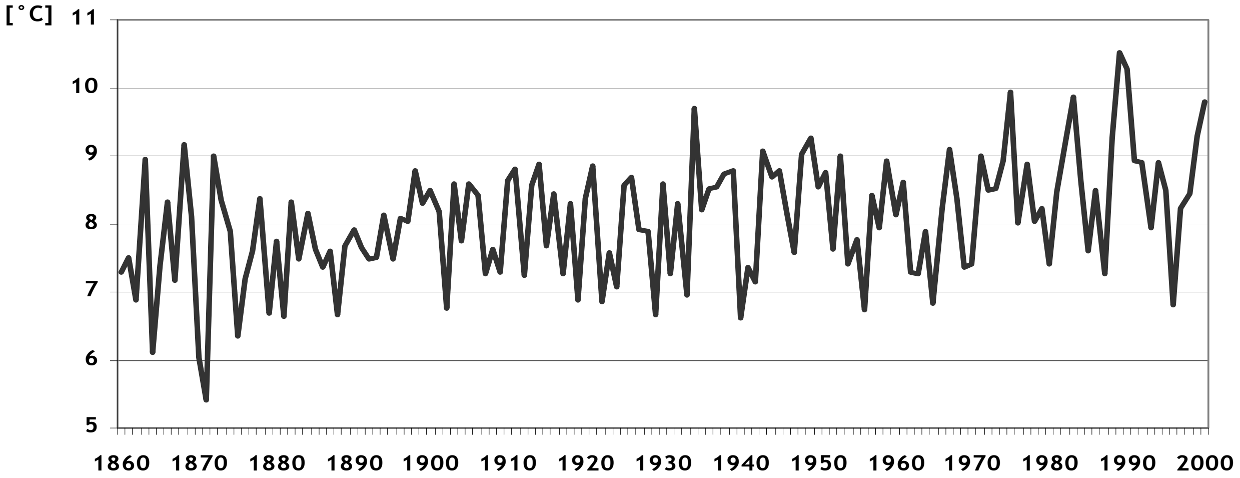


*Figure 2: Air temperature (°C) - upper panel, and precipitation (mm) - lower panel, from the meteorological station in Bydgoszcz (1951-1980).*

Site conditions at GFI are also characterized by a very low amount of precipitation. For the 1951–1980 period there were less than 550 mm per year. Most of the annual precipitation (~335 mm) falls during warm half of year (April- September) coinciding with the vegetation season. For the study area water shortages are typical. Precipitation at GFI is highly variable annually and also during the warm season; from year to year this variability can even reach 100–400 mm.



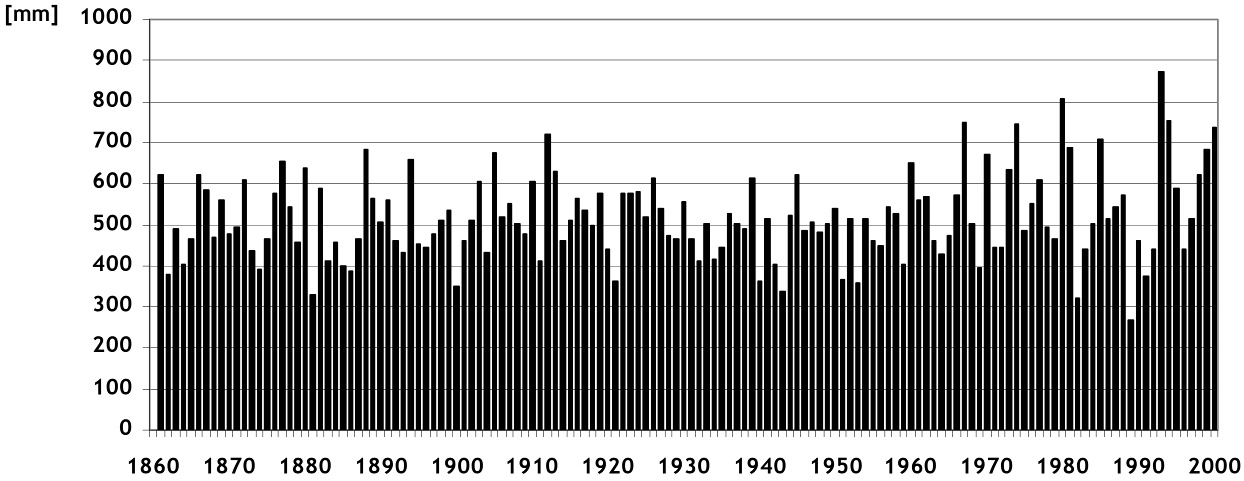


*Figure 3: Mean annual air temperature (1861-2000) – upper panel, and annual totals of precipitation (1861-2000) – lower panel, from the meteorological station in Bydgoszcz.*

Data from meteorological station in Bydgoszcz were used for dendroclimatological analyses. Year-to-year air temperature variation over the 1861-2000 period shows a positive, statistically significant trend (Fig. 3). For precipitation there is also a long-term positive trend, but it is not statistically significant.

## Material and methods

The research site is located in "Długi Bród Nature Reserve" in the Gołąbki Forest Inspectorate. A total of 17 samples were taken from 10 trees by means of a Pressler borer. Tree-ring widths were measured using CooRecorder computer programs and next, in order to assess the cross-matching between the samples, CDendro (www.cybis.se) and Cofecha programs (Holmes 1986, Grissino-Mayer 2001) were applied.  The samples were not visually crossdated. Chronology was constructed with only 4 samples. The age trend was removed due to standardization.

In the next step, the chronology was transformed using the CRONOL program (Dendrochronology Program Library DPL, routine CRN; Holmes 1994). Application of the autoregressive procedure (modelling) to the detrended tree-ring series produced a residual version of the chronologies.

In order to find climate/growth dependence, the climatic data were correlated with pine residual chronology (GOLCRES).

## Scots Pine chronology in GFI

The age of the oldest tree in GFI is about 240 years. However the standard chronology contains 213 years. The mean sensitivity for residual chronology reached 0.272 (Tab. 1). This value is typical for trees in old stands or in stands threatened with anthropogenic-pressure. A long-term increase in the mean sensitivity is found, and is likely caused by a combination of pollution in industrial period and the age of the trees (Zielski 1997).

*Table 1: Statistics of raw data, standard and residual chronology for Scots pine in the Gołąbki Forest Inspectorate.*

| Chronology | Number of tree-rings | Mean [mm] | Median | Mean sensitivity | Standard deviation | 1-order autocorrelation |
|---|---|---|---|---|---|---|
| GOLC08A | 213 | 1.305 | 1.070 | 0.313 | 0.885 | 0.800 |
| GOLC08B | 213 | 1.209 | 0.870 | 0.352 | 0.977 | 0.800 |
| GOLC09A | 190 | 1.332 | 1.145 | 0.238 | 0.806 | 0.720 |
| GOLC09B | 173 | 1.454 | 1.290 | 0.263 | 0.801 | 0.830 |
| GOLOB | 213 | 1.325 | 1.094 | 0.292 | 0.867 | 0.788 |
| GOLE | 213 | 0.832 | 0.673 | 0.333 | 0.546 | 0.718 |
| GOLL | 213 | 0.509 | 0.395 | 0.465 | 0.400 | 0.690 |
| GOLCSTA | 213 | - | 0.937 | 0.214 | 0.397 | 0.700 |
| GOLCRES | 212 | - | 0.962 | 0.272 | 0.262 | -0.100 |

GOLC08A, GOLC08B, GOLC09A, GOLC09B - samples sequences
GOLOB, GOLE, GOLL - ring widths, earlywood and latewood chronologies
GOLCSTA, GOLCRES - standard and residual chronologies

## Climate — tree-growth reaction

Scots pine in GFI is sensitive to thermal conditions at the end of winter and the beginning of spring (corr. coeff. 0.24 and 0.26 – February and March respectively). For precipitation, statistically significant correlation coefficients of 0.16 and 0.24 were obtained for May and July, respectively (Fig. 4). This is typical climatic response for this species in Polish Lowland (Zielski 1997, Wilczyński 1999, Feliksik et al. 2000, Wójcik et al. 2000, Błaszkowski 2002, Cedro 2004).

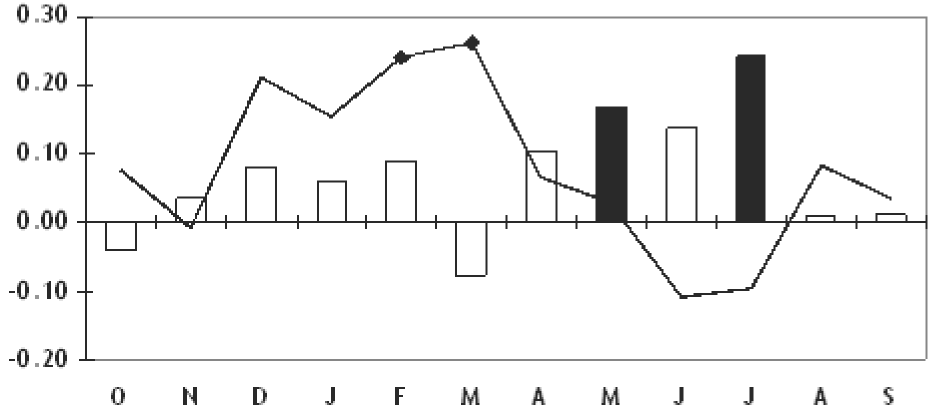


*Figure 4: Results of correlation in 1861-2000 between weather conditions and GOLCRES chronology for temperature (lines) and precipitation (bars). Correlation coefficients significant at the 95% confidence level are indicated by the filled symbols.*

Even though these correlations are significant they are still low, because of the amount of individual chronologies used to conduct the residual chronology.

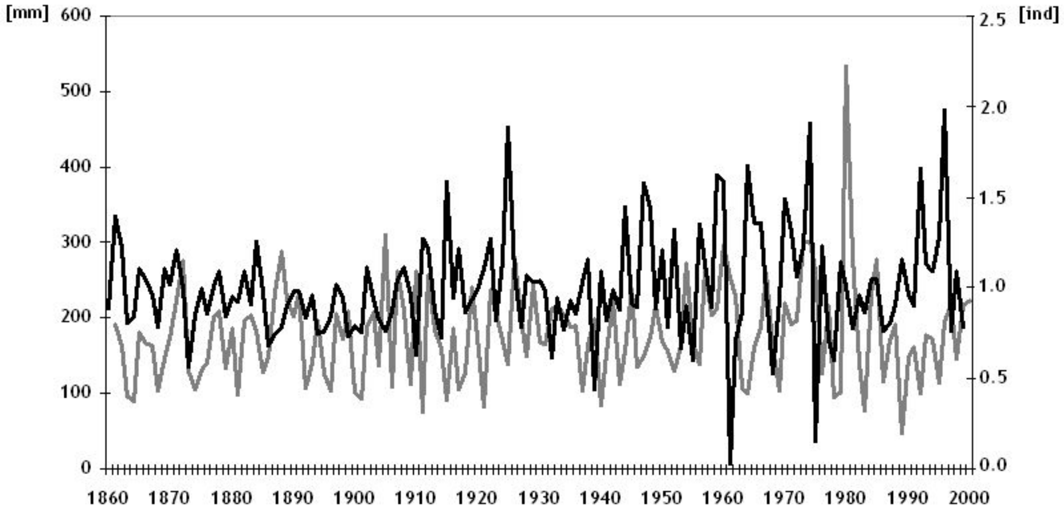


*Figure 5: Residual chronology (black line) and precipitation (grey line) for GFI in period 1861-2000.*

For pine in GFI the strongest influence on radial growth have precipitation. This influence is both, negative or positive depended on local environmental factors (Fig. 5). Most likely the main cause is hunting of ground water level. Tree growth was stimulated by high precipitation in periods 1961-1965 and 1975-1979. In periods 1888-1891 and 1932-1938 high precipitation suppressed tree growth. However the trees in GFI during last twenty years of 20th century produced narrow rings without any significant relation to amount of precipitation, which must be explained by ageing process.

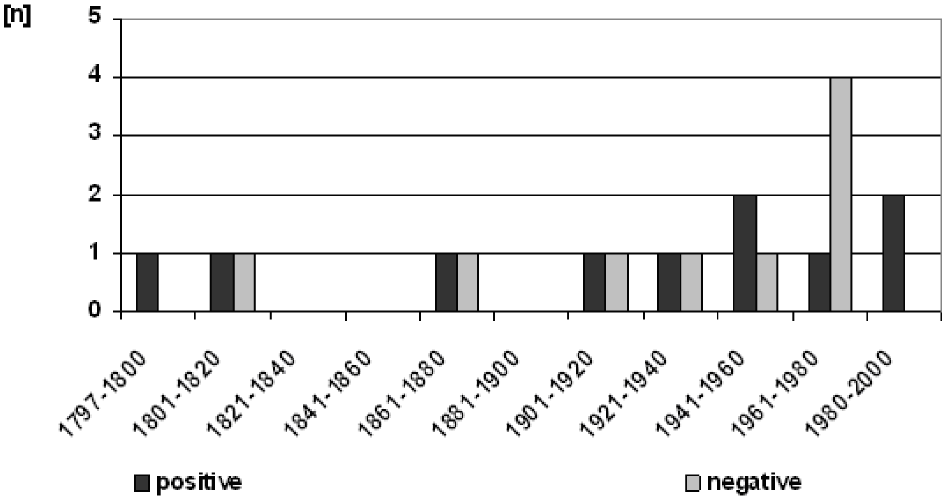


*Figure 6: Scots pine pointer years in Gołąbki Forest Inspectorate.*

Between 1861-2000 tree-growth 24% of tree growth variation can be explained by climate. This relation is very variable and depends on analyzed period. For the 1940–1979 period, this relation has the highest value – 65%. In this short period, we found 11 pointer years. This is half of the 22 pointer years observed during the 1789-2000 period (Fig. 6).

## Conclusions

After the period with very high correlations with climate (1940-1979), came after period with loss of climate signal in tree-ring sequence (two last decades of 20th century), caused by ageing process.

Factors limiting tree-ring growth in GFI are: air temperature at the end of winter and beginning of spring, and summer precipitation. After the period with very high correlations with climate (1940-1979), came after period with loss of climate signal in tree-ring sequence (two last decades of 20th century), caused by ageing process. The strongest correlations between climate and tree-ring growth occurred during periods with high temperature and precipitation variability. For most cases of pointer years, the cause was precipitation (local environmental factors). The strongest correlations occurred between climate and tree-ring growth during periods with high temperature and precipitation variability.

## Acknowledgements

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# Growth climate response at high elevation: comparing Alps and Himalayas

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## Introduction

High altitude ecosystems and alpine tree-lines are important indicators of environmental changes since they are highly sensitive to environmental conditions. Therefore, the dendrochronological investigation of samples collected at high-altitude from timber or tree-line species may produce long term proxy data which, once combined with long term instrumental climate records, can provide excellent information on global climate variability (Carrer & Urbinati 2006).

Here we present the results of a study on the growth climate response of two high-elevation species growing along the Himalayan mountain range: the Himalayan fir (*Abies spectabilis* (D. Don) Spach) and the Himalayan birch (*Betula utilis* D. Don). We sampled more than 50 trees and compared the results with those previously obtained from two other tree-line and climate-sensitive species, studied at 30 sites in the Alps: the European larch (*Larix decidua* Mill.; Carrer & Urbinati 2006) and the Swiss stone pine (*Pinus cembra* L.; Carrer et al. 2007).

*Abies spectabilis* is a large conifer, a high-elevation fir spread all over the Himalayan range. It is growing in the sub-alpine forests, characterized by low branching and dense foliage and it is usually associated with *Betula utilis* (Yadav et al. 2004). Concerning dendrochronology, *A. spectabilis* is currently the most intense studied among the Himalayan species and the longest chronology, available at the ITRDB, is 600 years long (Cook & Krusic 2003).

*Betula utilis* is a typical tree-line species of the Himalayas and Karakorum. At the Nepali sites, we have found it in mixed stands with *Abies spectabilis* and *Rhododendron ss. pp*.

Tree rings of *B. utilis* have only been studied little yet. The only work available so far is the research of Bhattacharyya et al. 2006.

This one could be considered a preliminary study on the dendroclimatic response of two species living at the highest tree-line on Earth, the Eastern-Himalayan one. Still very little is known about the growth climate response of the species living in the Himalayan range, but we could suppose various similarities in the growing patterns due to the comparable ecological features of the Himalayan and the Alpine tree-lines. Both these ecotonal environments, in facts, should be considered driven by equal limiting factors (Körner 1999). One of the first clues of these similarities are the comparable mean temperatures recorded all over the year for the two alpine ecosystems we compared (Figs. 4 & 5). Studies on the Alpine species we have chosen for our confrontation (Carrer & Urbinati 2006, Carrer et al. 2007) have underlined, for example, the high correlation between the temperatures of June and July and the growing pattern detected in tree-rings of *Larix decidua* and *Pinus cembra*. Therefore, we could expect that similar temperatures recorded in high Himalayas could lead to similar growth climate responses also for those Himalayan species and sites which have the same ecological value of the Alpine ones. By contrast, big dissimilarities exist among the precipitation trends of the two mountain chains, since in the Nepali sites there is the 75% of the annual rainfall concentrated between May and September, while over the Alps the spring and the autumn months are those with the highest levels of precipitations (Figs. 4 & 5).

So, taking advantage of the well studied climate growth behaviour of the Alpine species, we tried to single-out any possible common or uncommon response of the less studied Himalayan species we have decided to sample and compare, in order to start investigating a little more the dendrochronological features of the trees living at the highest tree-line on Earth.

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Set by single points, the aims of this study are:
- to investigate if the Himalayan tree-line species are as sensitive to the climatic conditions as the Alpine ones;
- to search for correspondences in the growing patterns, correlated to the ecological similarities of the Himalayan and Alpine tree-lines;
- to search for differences in the growing patterns, correlated especially to the dissimilarities among the climatic regimes;
- to improve the knowledge of the climate growth response of two Himalayan tree-line species.

## Methods

The samples have been collected in April 2008, during the scientific expedition of the University of Padua, organized within the project *“Impact of climate change in vegetation distribution on Sagarmatha National Park”*.

The survey has been conducted in the Khumbu Valley (North-Eastern Nepal), right along the trekking route to the Mount Everest South face Base Camp. Two were the sites chosen for the research, located at very high elevation (from 3800m asl to 4100m asl, along the tree-line), at the highest altitudes reached by the subalpine forest on Earth. The trees we have sampled grow in forest stands close to the villages of Pangboche and Dole, at 27° 70’ Lat. N, 86° 70’ Long. E. The sites are approximately 5km apart from each other, as the crow flies, at the left riverbank side of the Imja Khola Valley (facing North-West; here named as “Ama Dablam”) and at the right riverbank side of the Dudh Kosi Valley (facing North-East; named as “Dole”; Fig.1).

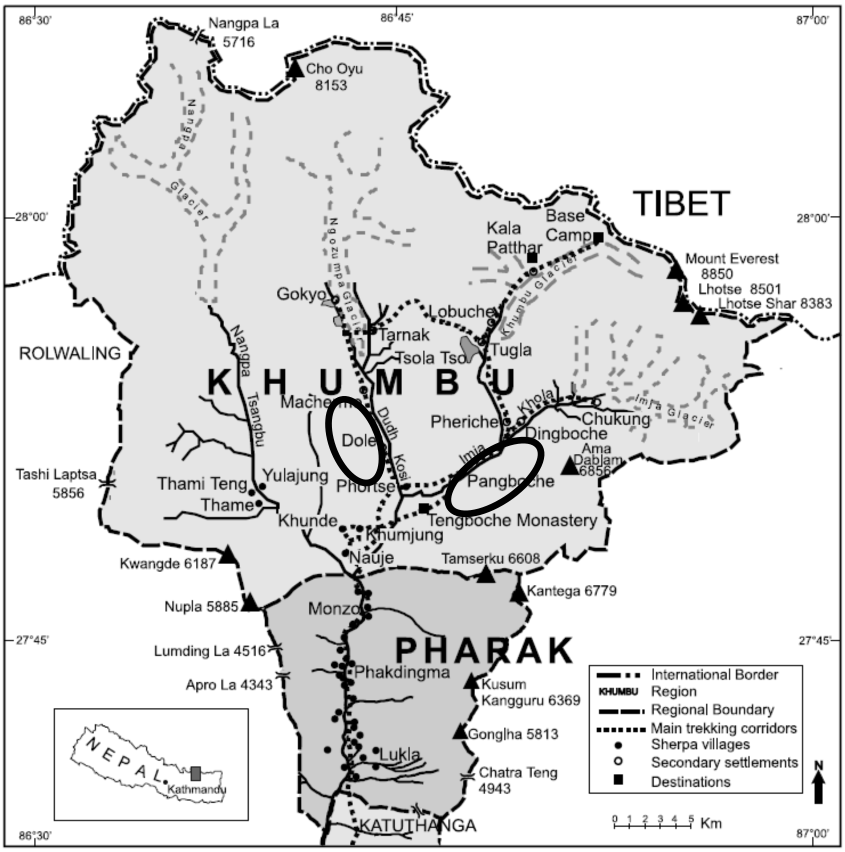

*Figure 1: Location of the sampling sites (within the ovals) in the Khumbu Valley. (Adapted from Stevens 2003).*

Following standard techniques (Phipps 1985), we collected at both sampling sites 2 cores of each tree, coring approximately at 1.3m above ground level, on the cross-slope sides of the trunks, when possible. When sampling the 20 trees per site and species, we paid attention, looking not only at the dimensions of the trees themselves, but also at their external morphology, in order to select the oldest individuals. The tree-ring samples were then mounted onto grooved boards, sanded (according to Stokes & Smiley 1968), and measured with 1/100mm accuracy, using the C.A.T.R.A.S. device (Aniol 1983). Crossdating and measurement accuracies were checked and confirmed using the COFECHA software (Grissino-Meyer 2001, Holmes 1983). Several descriptive statistics, commonly adopted in dendrochronology, were used to compare the two sites chronologies. The details of the tree-ring growth chronologies obtained from the respective sites are shown in Table 1.

Table 1: Descriptive statistics of the chronologies, presented by species and site. CL: Chronology length; MM: mean measurement; SD: standard deviation; *AC-1: first order serial autocorrelation; MS: mean sensitivity*

| | **Time-span** | **CL** | **# of cores** | **# of trees** | **MM (mm)** | **SD** | **AC-1** | **MS** |
|---|---|---|---|---|---|---|---|---|
| ABSB Ama Dablam | 1796-2007 | 211 | 26 | 16 | 0.94 | 0.41 | 0.85 | 0.18 |
| BUUT Ama Dablam | 1782-2007 | 226 | 23 | 14 | 1.05 | 0.61 | 0.79 | 0.27 |
| ABSB Dole | 1836-2007 | 172 | 24 | 16 | 1.3 | 0.50 | 0.80 | 0.18 |
| BUUT Dole | 1607-2007 | 401 | 23 | 12 | 0.86 | 0.51 | 0.75 | 0.28 |

To remove the biological growth trend as well as other low-frequency variations, the ring-width measurement series were standardized using the ARSTAN software (Cook 1985, Cook et al. 1990). In the present study we performed three different detrending methods, that is, the 50, 150, 300-yr smoothing splines (Cook E. R. & Peters K 1981).

One of the main problems for dendroclimatological studies in the High Himalayas is the availability of reliable and suitable instrumental data, since meteorological stations with long and homogeneous records (then appropriated for our kind of survey) are usually located far from the tree-ring sites and, comparatively, at lower elevation (Yadav et al. 2004). Hence, in order to have the longest data frame, possibly over 1 century, without too many missing data, we correlated the tree-ring series with climate data obtained from the CRU TS3 0.5° grids. This dataset ranges from 1901 to 2006 and is available at http://climexp.knmi.nl/getstations.cgi, both for the total monthly amount of precipitations and the monthly mean of temperatures.

On the contrary, the availability of appropriate instrumental meteorological data was not a problem at the European sites, neither for those where the *Larix decidua* climate-growth correlations were studied, located mainly in North-Eastern Italy (Fig. 2), nor for those of the Swiss stone pine, which is distributed widely in the Alps (Fig. 3). To asses climate–growth relationships (Fritts 1976) we used standard correlation function (CF) analysis. The statistical significance and stability of the CFs was evaluated with a bootstrap procedure with 1000 replications, throughout the computer program Symstat. CFs were computed using the ring width indexes as dependent variables and 24 independent variables (12 1-month time series each of temperature and precipitation) sequenced according to a “biological year” frequently adopted for Alpine species studies (Ettl & Peterson 1995, Carrer & Urbinati 2004), ranging from October of the year before growth (indicated as PYOCT “PREVIOUS YEAR OCTOBER”, in figures 8 and 9) to September of the year of growth (indicated as SEPT, in figures 8 and 9). Standardized correlation coefficients were obtained by dividing the mean correlations by their standard deviations after the bootstrap replications. They express the significance of monthly parameters and when the values are above I2I should be considered significant at P<0.05.

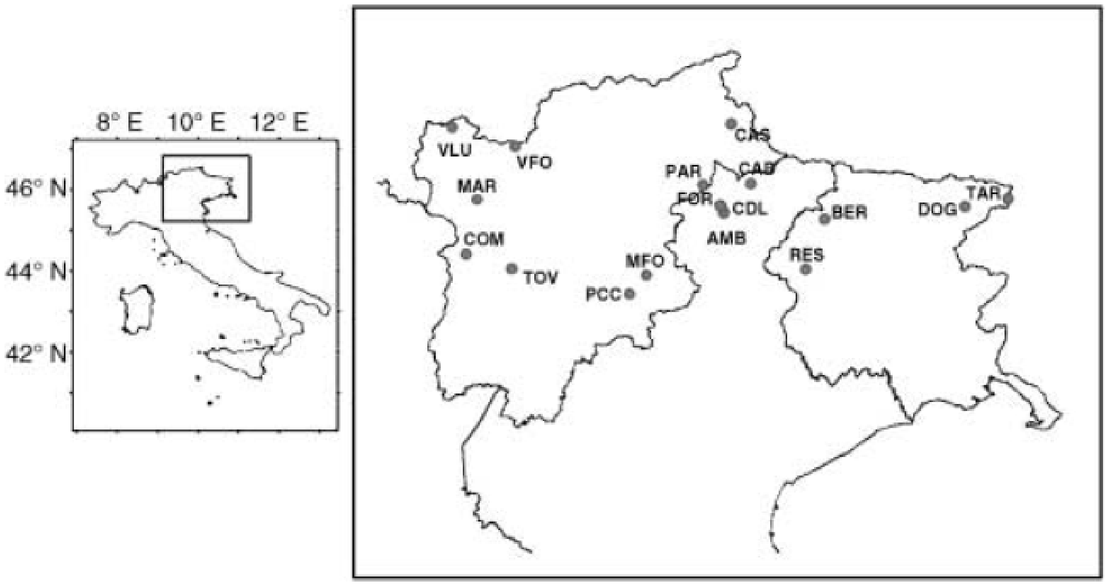

*Figure 2: Location of the Alpine Larix decidua study sites (from Carrer & Urbinati 2006).*

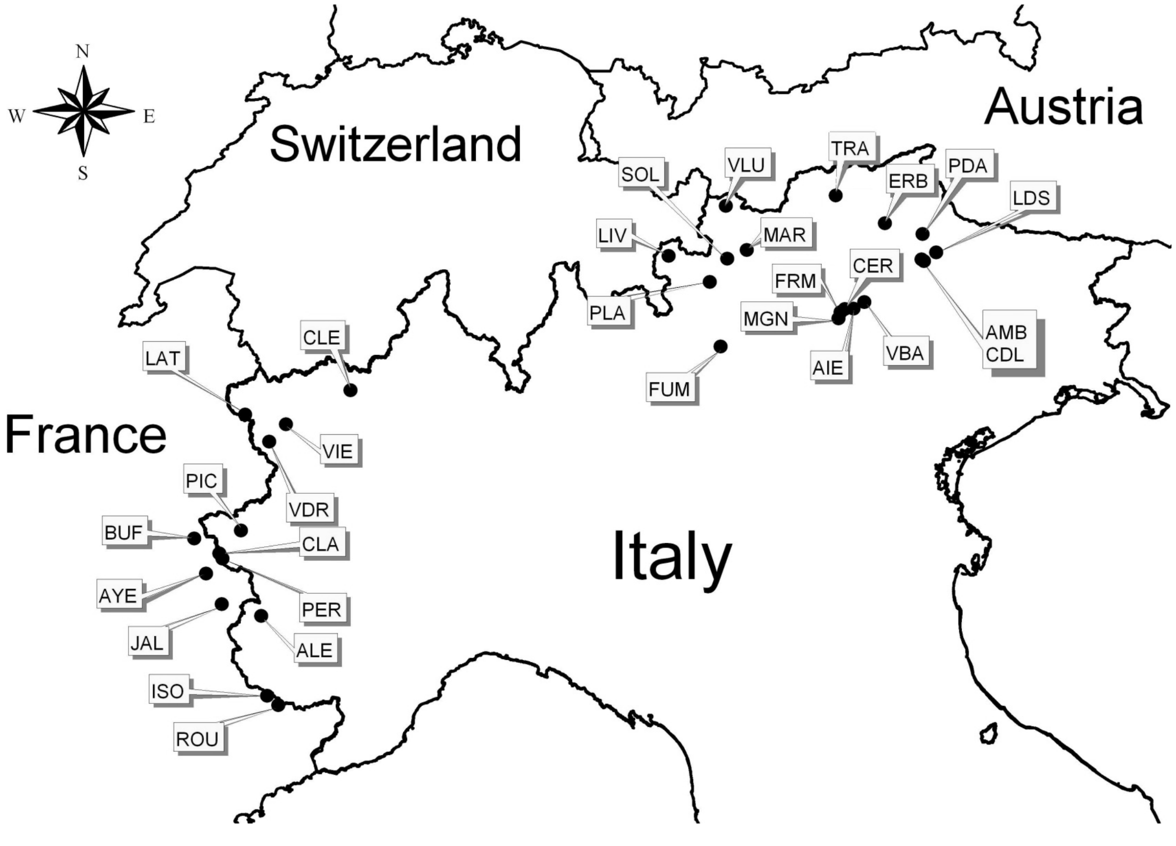

*Figure 3: Location of the Alpine Pinus Cembra study sites (from Carrer et al. 2007).*

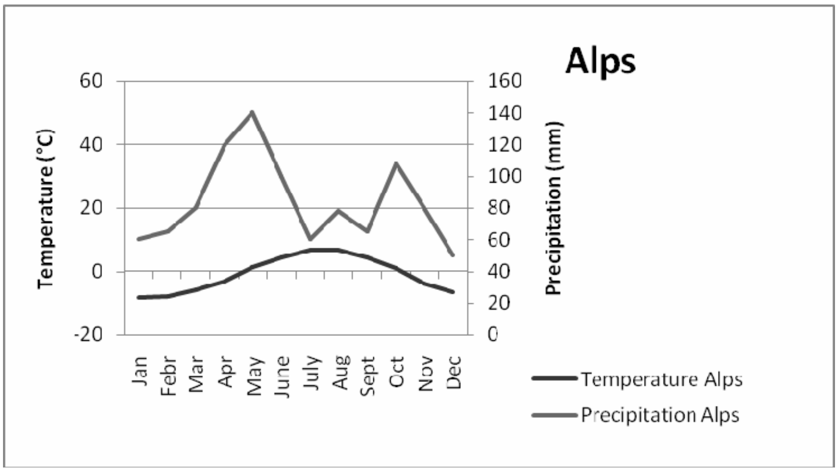

*Figure 4: Monthly means of temperature and precipitation for the Alpine sites (adapted from Carrer et al. 2007).*

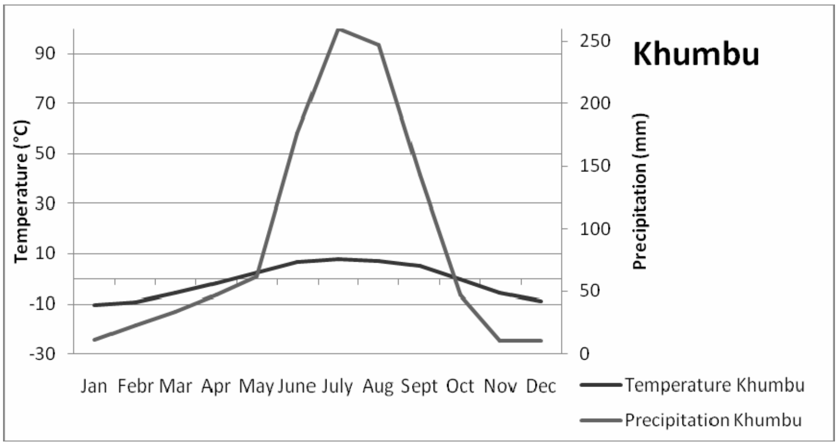

*Figure 5: Monthly means of temperature and precipitation for the Himalayan sites.*

## Results and discussion

The Himalayan data were compared with those of the two high elevation conifers of the Alpine range. The European larch chronology we considered comprises over 400 series, while the *Pinus cembra* data are derived from more than 900 cores collected all over the Alps. Table 2 shows the descriptive statistics for all the compared chronologies. Since the lower sampling depth of the Himalayan chronologies would have effects on their descriptive statistics, making any comparison among the Alpine and the Himalayan data not very reliable, here the Himalayan series are presented just species by species and not also site by site.

*Table 2: Descriptive statistics of the Alpine and Himalayan chronologies, presented by species and site. MM: mean measurement in mm; SD: standard deviation; AC-1: autocorrelation-order 1; MS: mean sensitivity; eps: expressed population signal.*

| | **Time-span** | **# of series** | **MM** | **SD** | **MS** | **AC-1** | **Rbar** | **eps** |
|---|---|---|---|---|---|---|---|---|
| Alps PICE | 961-2003 | 934 | 0.95 | 0.426 | 0.197 | 0.796 | 0.178 | 0.944 |
| Alps LADE | 1515-2008 | 447 | 0.768 | 0.386 | 0.354 | 0.616 | 0.561 | 0.986 |
| Khumbu BUUT | 1607-2007 | 46 | 1.038 | 0.595 | 0.273 | 0.768 | 0.234 | 0.907 |
| Khumbu ABSB | 1796-2007 | 50 | 1.225 | 0.485 | 0.177 | 0.802 | 0.117 | 0.776 |

Among the Himalayan chronologies, the high sensitivity and dendrochronological potential of the birch data is marked by the values of mean sensitivity (MS) and expressed population signal (EPS) obtained for this species. Birch's MS is comparable with the values got in Europe for larch: one of the most sensitive alpine species for studies in dendroclimatology. EPS, even though the number of the series is definitely lower than those analyzed for the european species, is anyway similar to the values of the larch and the stone pine chronologies and, overall, higher than 0.85, considered as a reasonable threshold (Wigley et al 1984). Moreover, looking at the only dataset available in literature for *B. utilis* (Bhattacharyya et al. 2006), both MS and EPS obtained from the analysis of the cores we collected in the Khumbu Valley agree with those presented by the Indian researchers for the samples collected in subalpine forests in Western Himalaya. The analysis of the *A. spectabilis* descriptive statistics gives evidence of a lower dendrochronological potential of this dataset. This lower "quality" is probably due to the high number of disturbances (fires, firewood and timber logging) that could have affected the oldest individuals of spruces throughout the centuries. These are kinds of low-frequency variations difficult to remove throughout the techniques used in dendrochronology. The higher sensitivity of the birch chronologies is also displayed graphically by the figure below, where the four Himalayan chronologies are presented site by site (Figs. 6 & 7).

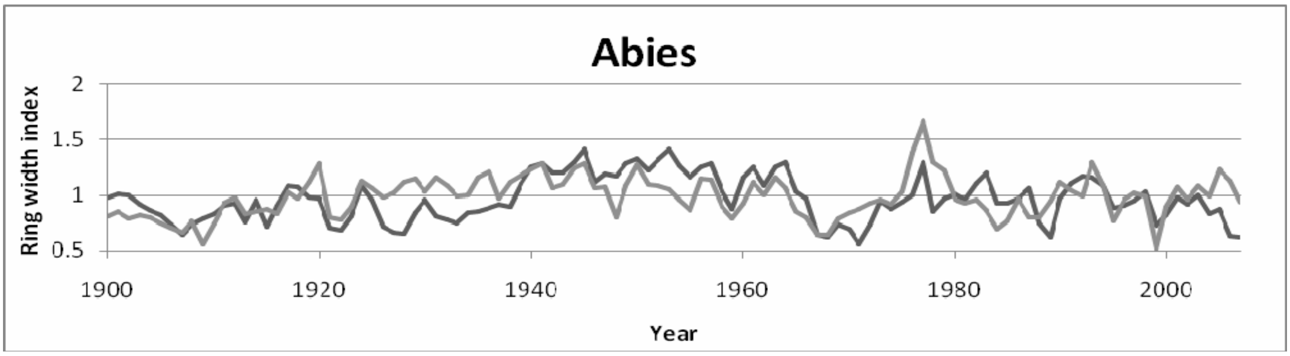

*Figure 6: The Abies spectabilis standardized chronologies.*

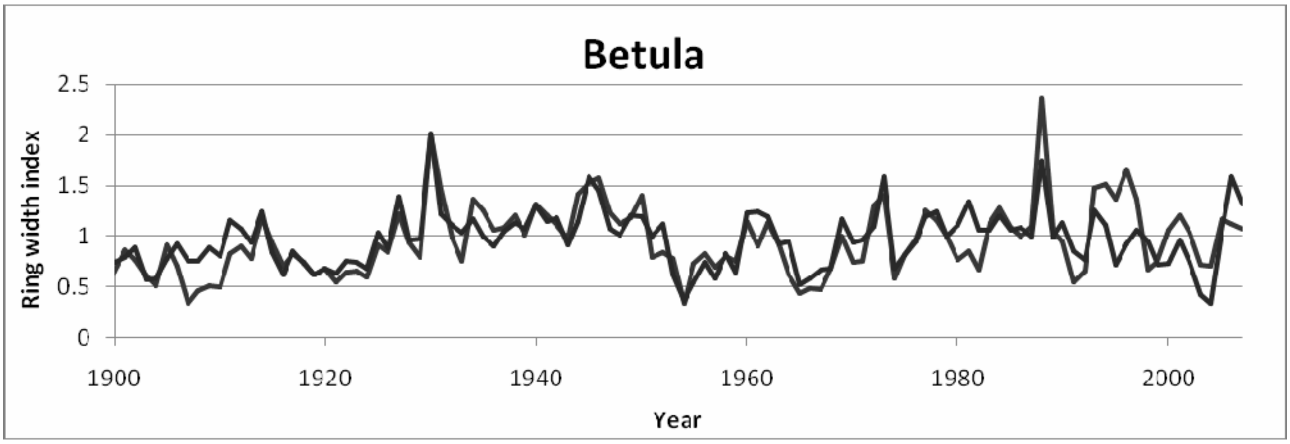

*Figure 7: The Betula utilis standardized chronologies. Please note the higher variability of the birch data indicating higher sensitivity.*

Reasonably, *B.utilis* shows also a clearer response to climate in comparison with *A. spectabilis*. Spruce almost never reaches significant values in the CF profiles we obtained, as shown in the summary graphs for precipitation and temperature we present here (Figs. 8 & 9). These outputs derives from the analysis of the 300-yr detrended chronologies, those which led us to the best results when comparing the response to climate for all the Himalayan and Alpine species we dealt with. Comparing the Himalayan and the Alpine scenarios, the CF profiles of figures 8 & 9 show that a possible common influence of climate on the growth of the four high-altitude species should be attributable to temperature of the growing season months, especially July and August, while it is not possible to individuate any common trend due to a similar response to precipitation.

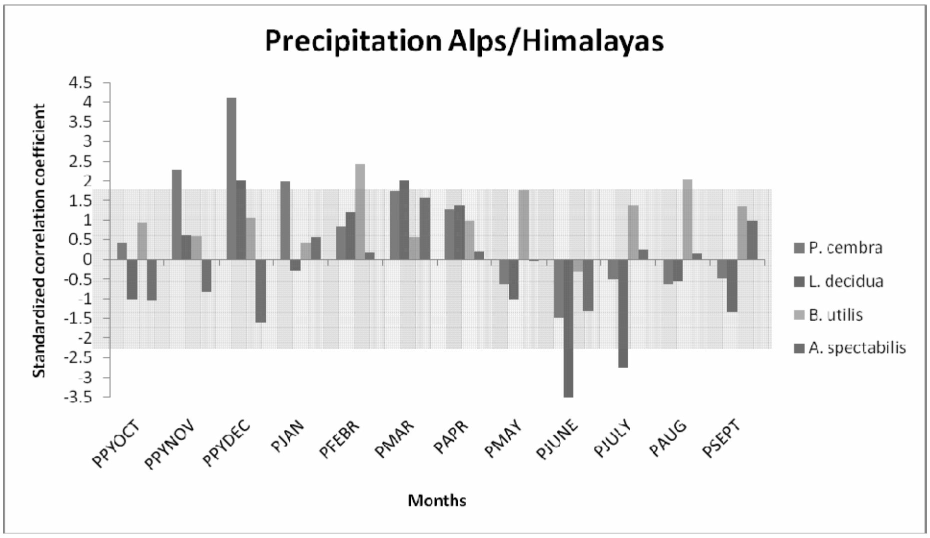

*Figure 8: Correlation functions of the Alpine and the Himalayan species with precipitation. Values above I2I are significant at P<0.05. Letter P in front of the months' name stays for "Precipitation".*

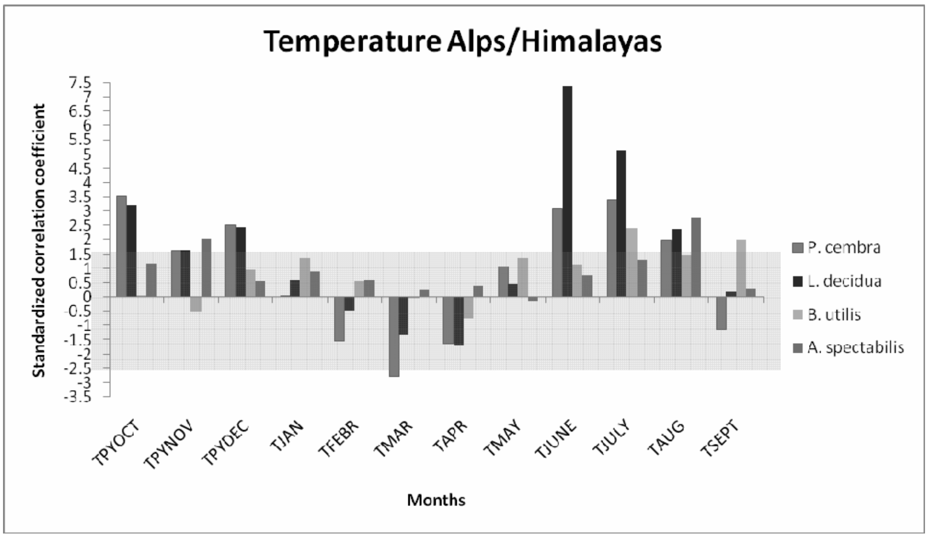

*Figure 9: Correlation functions of the Alpine and the Himalayan species with temperature. Values above I2I are significant at P<0.05. Letter T in front of the months' name stays for "Temperature".*

The better quality of the dendrochronological data we handled for the Alps and the higher availability of long and homogeneous meteorological records in Europe are most likely responsible for getting more evident and robust signals of climate-growth relationships in the Alps than in the Himalayas.

The great difference existing between the Alpine precipitation regime and the Himalayan one, driven by the monsoon, could be a first explanation of the impossibility to find any pattern of a common response to the annual rainfall in the two high-altitude ecosystems.

Nevertheless tree-ring growth of all the species we considered appeared to be correlated with the growing season temperatures. Therefore, the growing patterns of trees in natural environments such as the European Alps subalpine forest and the Himalayan one (so far away from each other and affected by completely different precipitation regime, but so close from an ecological point of view) seem to be similarly driven by a common climatic factor, that is temperature.

Once again could be confirmed that temperature has to be considered as a limiting and a very important parameter influencing radial growth in high-altitude forests, even at a global scale level when comparing similar ecosystems.

## Conclusions

This preliminary examination documented that Himalayan high-altitude trees, and among them birch especially, give evidence of their sensitivity to the climatic conditions, as their Alpine counterpart. However, differences in the growing patterns, due to the corresponding dissimilarities among the climate modes influencing the alpine and the Himalayan areas, have been singled out. Particularly, it was not possible to find any common pattern between Alpine and Himalayan species in the response to the rainfall, most probably due to the great difference existing between the Alpine precipitation regime and the Himalayan one, driven by the monsoon.

A common growing pattern for the high altitude ecosystem of Alps and Himalayas is more evident within the response of the tree-line species to temperature of the growing season.

Unfortunately, the lower quantity and quality of the dendrochronological surveys realized at the high Himalayan altitudes, because of all the disadvantages and the difficulties researches could still find there and the lack of long and reliable meteorological records for the Himalayan sites, represent a big issue to get an ecological interpretation of the dendrochronological datasets as good as that one obtained for the European region. Further works could focus on *B. utilis* tree-rings datasets, since this species looks to be really sensitive to climate conditions and suitable in making profitable scientific comparisons with ecologically similar and better known environments, such as the Alps.

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# Climate-growth relationships of Norway spruce in north-eastern Poland

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## Introduction

Tree growth depends on many factors with climate usually being considered the most influential one. The course of weather elements such as temperature, precipitation and moisture availability, sunshine duration or even snow abundance, that exhibit various pace and intensity, affects tree-ring formation in a different way (Fritts 1976, Schweingruber 1996). These meteorological driving forces originate very often from large-scale interactions between oceans, atmosphere and land that are transferred into local ecological systems affecting various processes occurring within the latter (Ottersen et al. 2001). Moreover, these widely used climate descriptors do not explain the whole variability observed in tree-ring width series. Thus it seems that there are other, less general or more local, features that affect the tree-ring formation.

Habitat type described as the function of site fertility and moisture availability may sharpen or soften the influence of climate on tree growth because of its variability. Sites with high moisture content in the soil may contain enough water to reduce unfavourable effects of low precipitation or high temperature, while trees on drier sites may suffer significant decrease in growth or even stop growing (Schweingruber 1996). To reveal these relationships may help with better understanding the ecological factors that govern the process of tree growth.

Although topic of growth/climate relationships has already gained a lot of interest for Norway spruce, the influence of site conditions has been investigated widely mostly for mountain areas (e.g. Neuwirth et al. 2004, Savva et al. 2006, Levanic et al. 2009). Studies regarding lowlands had also been performed (Zielski & Koprowski 2001, Koprowski 2003, Koprowski & Zielski 2006, 2008); however analyses of the role of the habitat concerned either individual locality (Bijak 2007) or specific subject – e.g. drought (Vitas 2004).

The objective of this study was to determine climate-growth relations for Norway spruce (*Picea abies* (L.) Karst.) growing in north-eastern Poland and investigate the role of the habitat type in modification of the trees response to the climate conditions within the locality and between analysed sites.

## Material and methods

Study material was collected in three major forest complexes representing the boreal range of Norway spruce natural distribution in Poland, i.e. Augustowska, Knyszyńska and Romincka Primeval Forests (hereinafter indicated as PA, PK, PR respectively; Fig. 1). Four habitat types characterised by different fertility and moisture availability were selected. According to the classification used in Polish forestry they belonged to the fresh mixed coniferous (BMsw), fresh mixed deciduous (LMsw), swampy mixed deciduous (LMb) and fresh deciduous (Lsw) forest habitat types. On each of 12 study plots 15 dominant, healthy and undamaged trees were sampled. One increment core per tree was taken with Pressler borer from the circumference at the breast height. The cores were sanded with finer grade until the tree-ring boundaries became easily distinguishable and then scanned. CooRecorder image analysing program (www.cybis.se) was used for measuring tree-ring widths to the nearest 0.001 mm. Climate data used in this study originates from the Climate Research Unit and Tyndall Centre resources (www.cru.uea.ac.uk, Mitchell & Jones 2005). High resolution (0.5°) grid data set (CRUTS 2.1) provided mean monthly air temperature and precipitation.

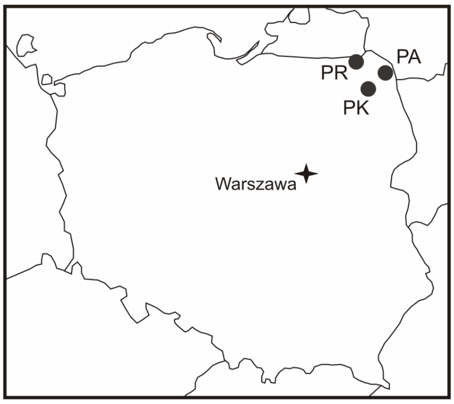

*Figure 1: Location of study sites.*

Individual series were cross-dated visually with the CDendro (www.cybis.se) software. The synchronisation was checked with COFECHA program (Holmes 1999, Grissino-Mayer 2001). Series that showed dissimilarity were excluded from the further analysis as they might limit the common signal exhibited by the chronologies. In total, 139 individual tree-ring width series was used in the chronology forming. Chronologies were constructed according to the conventional procedures (Cook & Kairiukstis 1990). Standard and residual chronologies were computed for individual study plots with CRONOL software (Holmes 1999).

Dendroclimatological analyses were based on the response function concept (Fritts 1976, Cook & Kairiukstis 1990). Residual chronologies were correlated with the series of monthly values of temperature and precipitation. As the conditions in the period prior to the ring formation affect this process in a great measure (Fritts 1976), the analysis included thermal and pluvial conditions spanning from July of the previous growth year to September of the current growth year. DendroClim2002 (Biondi & Waikul 2004) software was used to calculate correlation coefficients. The analysis of the influence of the climate was performed for period of 1953-2002 to avoid the possible bias caused by large variability of juvenile growth of analysed trees.

## Results

### *Chronologies*

Standard and residual chronologies were built for each individual study site. Developed chronologies coved the period of 1849-2007 (Tab. 1, Fig. 2). The smallest average tree-ring width occurred on LMb habitat type and ranged from 1.35 mm (PR) to 1.90 mm (PA). In general, the widest rings characterise the most fertile habitat. Only at PA site, spruces from LMsw habitat turned to produce the widest rings (Tab. 1). The lowest standard deviation of raw measurement series was observed again on the most moist habitat type. Interestingly, in case of all habitat types PR locality shows the greatest variability in tree ring widths. Mean sensitivity values followed the same pattern as the average ring width (Tab. 1).

### *Climate-growth relations*

The strength of the influence of thermal and pluvial conditions on growth of Norway spruce in north-eastern Poland varies depending on localisation and habitat type, but no clear pattern can be observed. Proportion of tree-ring width variability explained by climate conditions that is expressed by determination coefficient in applied multiple correlation and regression model ($R^2$ in Tab. 1) ranged from merely 29% on PK2 up to 63% on PA1 sites.

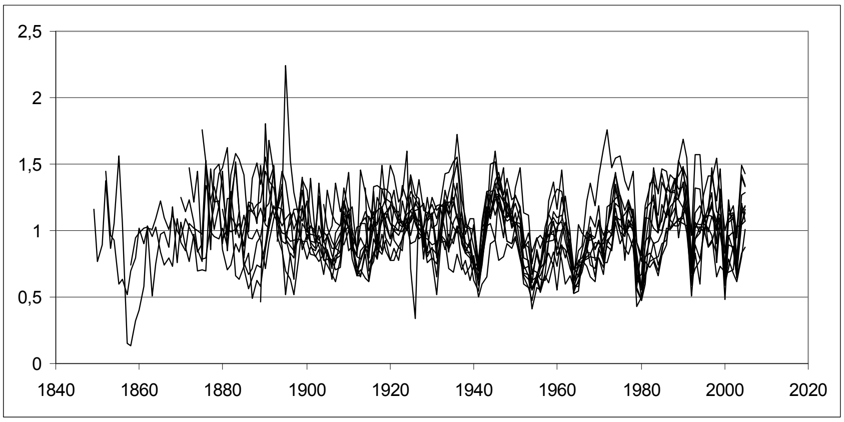

*Figure 2: Standard chronologies of Norway spruce from north-eastern Poland.*

*Table 1: Basic characteristics of the chronologies of Norway spruce from north-eastern Poland.*

| site | time span | # of cores | mean ring width | std. deviation | mean sensitivity | $R^2$ |
|---|---|---|---|---|---|---|
| PA1 | 1870-2007 | 10 | 1.75 | .506 | .194 | 63.45 |
| PA2 | 1849-2007 | 12 | 2.45 | .812 | .226 | 41.37 |
| PA3 | 1852-2007 | 11 | 1.90 | .441 | .154 | 46.24 |
| PA4 | 1880-2007 | 14 | 2.78 | .957 | .160 | 41.74 |
| PK1 | 1893-2007 | 10 | 2.09 | .929 | .173 | 35.07 |
| PK2 | 1914-2007 | 12 | 2.89 | 1.061 | .176 | 29.28 |
| PK3 | 1875-2007 | 10 | 1.63 | .615 | .165 | 49.37 |
| PK4 | 1857-2007 | 13 | 1.92 | .447 | .210 | 47.58 |
| PR1 | 1880-2005 | 12 | 2.28 | 1.434 | .159 | 42.82 |
| PR2 | 1904-2005 | 10 | 2.61 | 1.314 | .194 | 43.60 |
| PR3 | 1872-2005 | 14 | 1.35 | .412 | .146 | 38.73 |
| PR4 | 1889-2005 | 11 | 2.77 | 1.433 | .200 | 39.88 |

PA – Augustowska Primeval Forest, PK – Knyszyńska Primeval Forest, PR – Romincka Primeval Forest; 1 – fresh mixed coniferous (BMsw), 2 – fresh mixed deciduous (LMsw), 3 – swampy mixed deciduous (LMb), 4 – fresh deciduous forest habitat types (Lsw); $R^2$ – multivariate correlation determination coefficient [%]

Growth of analysed trees turned to depend on the thermal conditions in winter and early summer of the year of tree-ring formation as well as at the end of previous summer (Fig. 3a). Negative and significant correlation between tree-ring width and temperature was found out for June of the current growth year for majority of study plots at Knyszyńska and Romincka sites. The same kind of reaction was observed in all plots in Knyszyńska Primeval Forest as far as temperature in September of the year prior to the ring formation is concerned. In turn some sites from Augustowska and Romincka sites show significant positive correlation with temperature in February/March. Pluvial conditions were important in summer both in current growth year as well as in the year prior to the ring formation (Fig. 3b). Significant positive correlation of the tree-ring widths was observed for total precipitation in June for Augustowska and Romincka sites. The same type of relationship was found for July of the previous year for plots from Knyszyńska and, again, Romincka Primeval Forests.

## Discussion

Climate conditions do not seem to influence the radial growth of Norway spruce in north-eastern Poland in the great measure. The portion of the tree-ring width variance explained by temperature and precipitation equals 40-45% on average. Similar values were obtained by Bijak (2007) for

Borecka Primeval Forest, which is located westwards from the analysed sites. Koprowski (2003) reports much higher determination coefficients, while analysing trees growing in the whole boreal range of spruce in Poland.

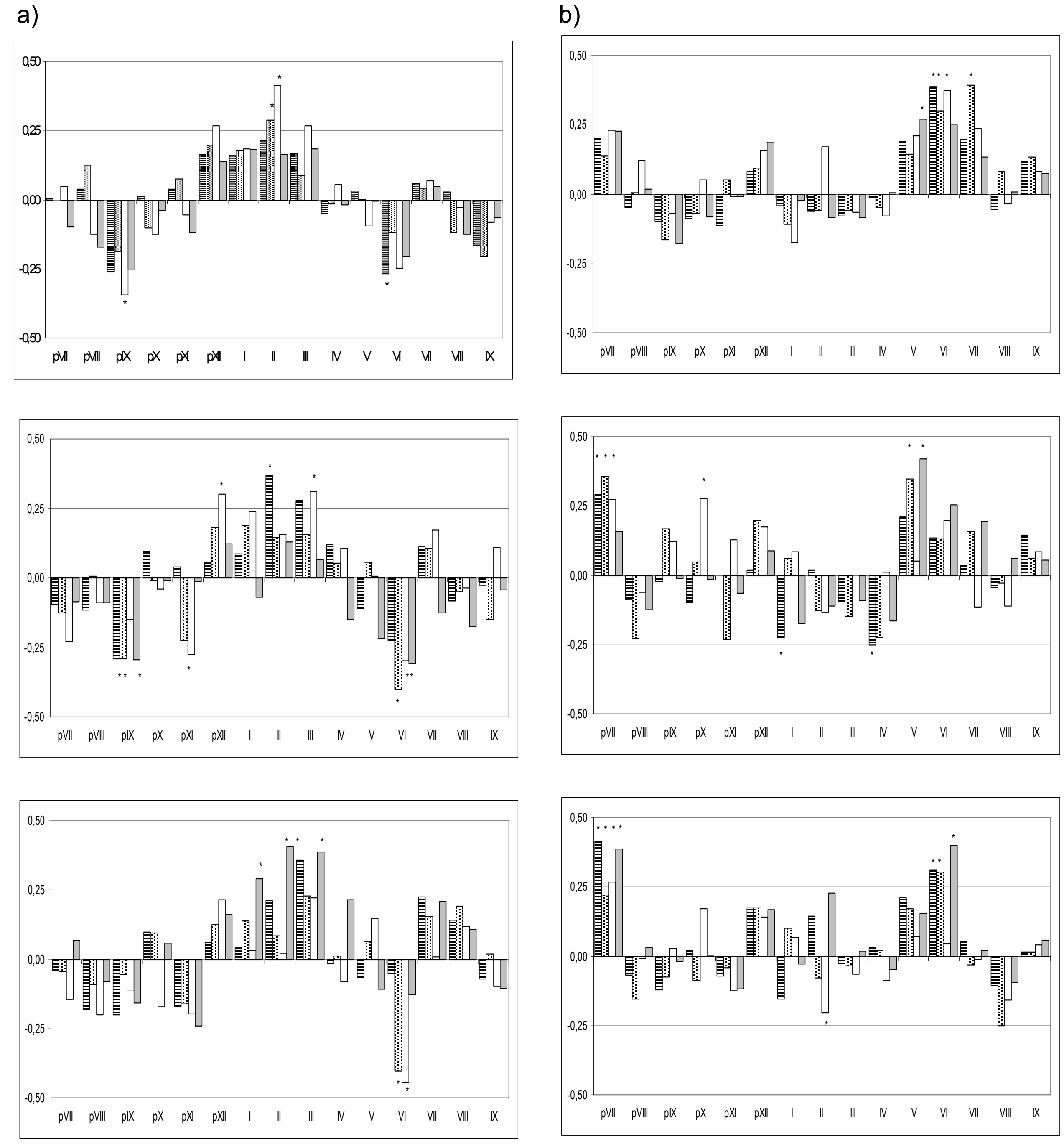

*Figure 3: Correlation coefficients between tree growth and mean monthly temperature (a) and total monthly precipitation (b). Each graph represents individual sites (PA, PK and PR from the top) and bars represent habitat types (BMsw, LMsw, LMB and Lsw from the left). Asterisk indicates values significant at 0.05 level.*

Also Koprowski and Zielski (2008) present values of 60% for site in Białowieża National Park. These differences may originate from applied climate data (e.g. different period, various range of months included in the analysis) and do not have to have any biological grounds. However, Mäkinen et al. (2003) stated that spruce under average climate conditions (and such exist in north-eastern Poland) responds less strongly to the climate than trees growing in extreme conditions (e.g. tree-line). Moreover, analysed stands exhibit similar character of the relationships with mean monthly temperature and precipitation to those reported for Norway spruce growing in Lithuania (Vitas 2004) and within boreal range of that species in Poland (Koprowski 2003, Koprowski & Zielski 2006), or, to some extend, in western Poland (Cedro & Cedro 2009).

Analysed spruces did not show very different reaction to thermal conditions with regard to the habitat type. It is rather the locality that causes various patterns of the response to temperature. No clear pattern connecting the moisture and fertility conditions can be found. Significant negative relation to temperature in September of the year prior to the ring formation observed for almost all sites (except from the most moist PK3) in Knyszyńska Primeval Forest is very interesting as such correlation has not been reported in the literature for the investigated area yet. Too hot beginning of autumn and, at the same time, of period when trees start to prepare to the winter dormancy may limit the uptake of nutrients and thus translate into smaller increment in the next year. Moist conditions of swampy mixed deciduous habitat type may soften this negative effect. On the other hand this situation does not occur in other analysed localities; hence no obvious conclusion can be drawn. Positive (very often significant statistically) relationship with temperature during December-February/March period can be observed at all sites and habitat types. This is rather strange for spruce is considered as a species tolerant to low temperature or winter frost (Feliksik 1972). Such pattern can probably be related to the thawing, which could provide enough moisture. That would also explain rather negative correlation with winter precipitation. However, this is the time of winter dormancy and no physiological reasons seem to explain this observation.

Presented results show significant response of analysed trees to water deficit in early summer of the year when the tree-ring is formed, and in the middle of this season, but in the previous year. Dependence of spruce growth on water availability in summertime was previously widely discussed and the vulnerability of that species to drought is well known (Zielski & Koprowski 2001, Solberg 2004, and Vitas 2004). Again, as in case of temperature, it is rather locality of the site that causes differences in this relationship. However, the most interesting is similar response of trees from Augustowska and Romincka as well as Knyszyńska and Romincka Primeval Forests, which is rather strange direction of similarity regarding localisation of the sites (Fig. 1).

## Conclusions

Norway spruce from north-eastern Poland finds the most favourable growth conditions during wet and mild summers. This general pattern is independent from the habitat type. Climate-growth relationships of analysed species seem to depend in greater measure rather on spatial distribution of climate variables than on local moisture and fertility conditions.

## Acknowledgments

The author is grateful to all people who supported the field works in Augustowska, Knyszyńska and Romincka Primeval Forests with their labour as well as administrative help and co-operation.

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# Austrian pine (*Pinus nigra* Arnold.) tree-ring width chronology from northeast Albania – preliminary results

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## Introduction

Austrian or Black pine (*Pinus nigra* Arnold.) is a widespread species on the Balkan peninsula and is one of the most important tree species in Albania. According to data of the last National Forest Inventory from year 2004, Albania has approximately 942.000 ha forest area with a standing volume of about 71 million m$^3$. Austrian pine stands account for 15 percent of the total standing volume of Albanian forests and 22.7% of total forest area of Albania. It spreads on a wide altitudinal range 900 to 2000 m above sea level and can measure as much as 55 m in height and up to 100 cm in diameter and can reach over 500 years in age on some extreme sites. Austrian pine is not a shade tolerant species, but it can resist low winter and high summer temperatures. It has a thick bark which makes it a bit more fire resistant than other tree species in the area. Natural ranges of distribution in Albania are the regions of Puka, Qafe-Shtama, Elbasani, Llogara, Mirdita and Fushe Arrezi.

Since Albania is considered to be a “white spot” on the dendrochronological map, we initiated a bilateral co-operation between Slovenia and Albania in 2006. We decided to analyze growth of Austrian pine (*Pinus nigra* Arnold.) on extreme sites, to produce a long chronology(-ies) and climate reconstruction for at least 100 years prior to the start of instrumental measurements, and to connect Albanian pine chronologies with other Austrian pine chronologies from the Balkan peninsula and neighbouring countries (Greece, Turkey, Macedonia, Bulgaria,…). In this paper, we present the first chronology of Austrian pine (*Pinus nigra* Arnold.) from Albania and its response to climate.

## Material and Methods

Our study site is located on a relatively steep, rocky slope with southern exposure in the Qafe-Sthame mountains (NE Albania) – see Figure 1. Elevation of the site is between 1050 and 1500 m a.s.l. Soil type is mountainous reddish-brown soils (Haplic Luvisoils) on ultrabasic rock formation. Typical for this type of soil is rich ground vegetation with Austrian pine as the main tree species. One of the main characteristics of this location is a high frequency of surface forest fires, which only burn forest undergrowth and surface litter, but inflict only minimal damage to the trees. All trees at this location have typical fire scars on the upper part of the trunk, but this influenced growth only limitedly: all trees were healthy, crown transparency was low and no other visible damages of the stem were detected. On this site, we selected 36 trees and took two 5 mm cores per tree perpendicular to the slope. Average diameter of the sampled trees was more than 52 cm and height between 20 and 25 meters.

Each core was mounted and sanded to a high polish following standard dendrochronological procedures (Stokes & Smiley 1996). Cores were then digitized using ATRICS® system (Levanič 2007) and annual radial growth was measured to the nearest 0.01 mm using WinDENDRO™ software. Each tree ring series was then visually crossdated in PAST-4 using both visual comparisons and well established statistical parameters, including $t_{BP}$ (Baillie & Pilcher 1973), Gleichlaufigkeitskoeffizient - GLK% (Eckstein & Bauch 1969), and Date Index - DI (Schmidt 1987). Values of $t_{BP}$ higher than 6.0, GLK% values higher than 65%, and DI values higher than 100 were considered significant. The ARSTAN programme (Cook 1985, Cook & Holmes 1999) was used to remove age trends in the ring width data and to build a site chronology. De-trending was achieved using a negative exponential or linear function. Indices were calculated as ratios between the actual and fitted values. Index values were then prewhitened using an autoregressive model selected on the basis of the minimum Akaike information criterion and combined across all series using bi-weight robust estimation of the mean to exclude the influence of the outliers (Cook 1985, Cook et al. 1990, Cook & Holmes 1999).

Signal strength was tested using Expressed Population Signal - EPS (Wigley et al. 1984, Briffa & Jones 1990). Only those series with a high common signal (EPS≥0.85) were included in the analysis. The detrended series from each tree were then averaged to form a site chronology, which was compared to climatic data sets. For comparison we used a 24 month long time window starting from January of the previous year until December of the current year. We used a local source of mean monthly temperature and monthly sum of precipitation from Kruje meteorological station (1951 - 1993). Because of the short observation period of this data set, we completed the analysis with 10'x10' gridded data from CRU TS 1.2 for the period 1901-2000 (Mitchell et al. 2003). Temporal stability of the climate signal was analysed using program DendroClim2002 (Biondi & Waikul 2004).

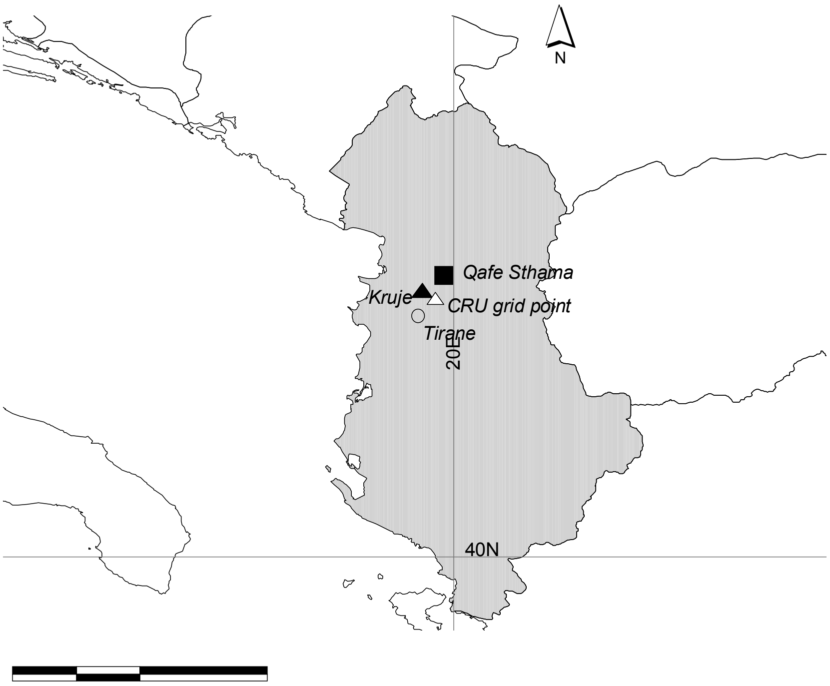

*Figure 1: Location of the research plot in Qafe Sthame mountains – black square. White circle marks the location of the Albania's capital Tirane. Black and white triangle marks locations of the Kruje meteorological station and CRU grid data point.*

## Results

### *Site chronology*

We compiled a 238 years long chronology spanning the period 1770-2007 with a replication of more than 8 trees from 1795 onwards (Fig. 2). Chronology is based on cores from 20 trees although we sampled 36 trees. Sixteen trees were not included into chronology due to different growth anomalies. Average age of the analyzed trees included into chronology was 186 ± 38 years and average tree-ring width 1.25 ± 0.83 mm (Tab. 1). Average correlation between trees was 0.552 which results in EPS values >0.85 from 1816 until 2007.

Comparison with Austrian pine chronologies from Bosnia and Herzegovina and Montenegro gave relatively high statistical values – with chronology from Montenegro $t_{BP}$ 5.50 and GLK% 63.50 and with chronology from Bosnia and Herzegovina $t_{BP}$ 4.92 and GLK% 62.80. This shows a good regional signal of the Albanian chronology and possibility to be included into a Austrian pine dendrochronological network for the Balkan peninsula.

*Table 1: Main statistical parameters of the raw tree-ring widths series (RAW) and both standard and residual chronologies (STD, RES).*

| | **RAW** | **STD** | **RES** |
|---|---|---|---|
| Time span | 1770-2007 | | |
| Total years | 238 | | |
| Number of trees in chronology | 20 | | |
| Mean age | 187 ± 38 | | |
| Mean | 1.25 | 1.01 | 1.00 |
| Standard deviation | 0.83 | 0.41 | 0.27 |
| Skewness | 1.67 | 0.72 | 0.30 |
| Kurtosis | 6.45 | 3.87 | 3.27 |
| Mean sensitivity | 0.25 | 0.25 | 0.28 |
| AC(1) | 0.80 | 0.68 | -0.02 |

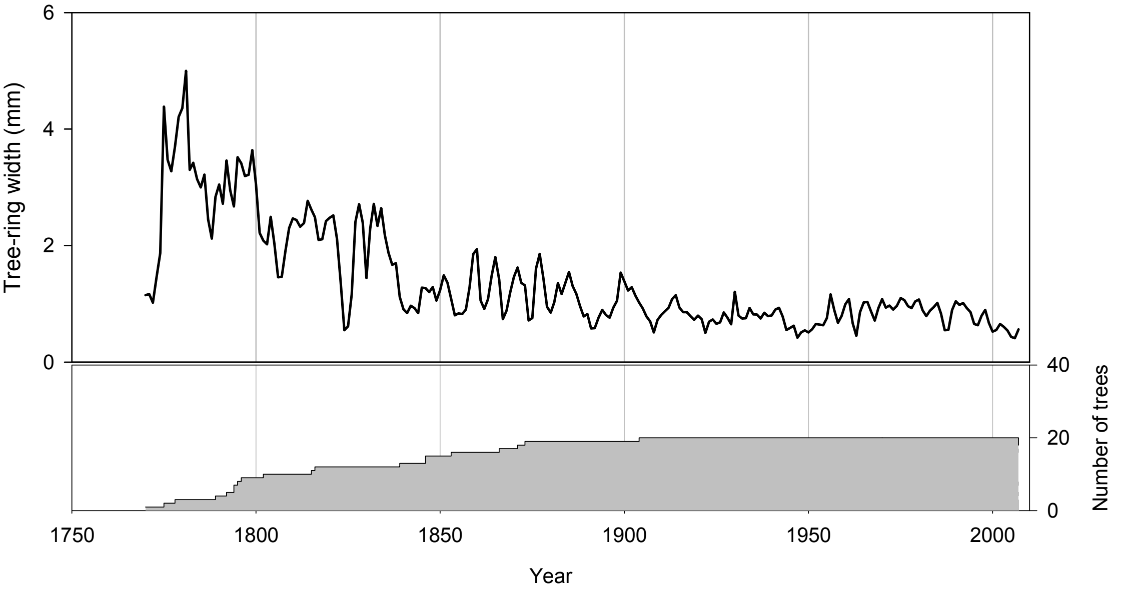

*Figure 2: Raw tree-ring width chronology of Austrian pine (Pinus nigra Arnold.) for the Qafe-Sthame mountains in NE Albania. Upper part of the figure is the raw tree-ring width chronology; lower part shows sample replication.*

### *Response to climate*

Response of Austrian pine to climate is strong. Simple Pearson's correlation coefficients between local climate data from Kruje and the site chronology showed a significantly ($p<0.05$) negative response to above average warmth in June and a significantly positive response to above average precipitation in June (Fig. 3a). Correlations with July and August mean monthly temperature are just below the threshold value, most probably because of the short climate record. When we combine June, July and August into a single variable we got a highly significant negative correlation of -0.40±0.13 ($p<0.05$). Previous year precipitation in August and September has a positive influence on tree growth in the current year (Fig. 3a).

Comparison between tree-ring width indices and CRU TS 1.2 gridded climate data for the 24-month time window showed that the correlations with temperature data were comparable to those with the local climate data set – Figure 3b. Temperature in June of the current year has a negative influence on growth if above average. July and August and previous August and September above average temperature also have a significantly ($p<0.05$) negative influence on growth. These correlations were not significant in the case of Kruje climate data set. Combined effect of current year June, July, and August temperature on tree-ring width resulted in much higher correlations (0.38±0.08; $p<0.05$) than each of the months separately, but still marginally lower than based on local meteorological data.

From all tested combination between tree-ring indices and precipitation, only current January precipitation has a significantly negative influence on tree growth. None of the other tested combinations were significant, but some, such as current year June, were just below the 95% significance level (which is similar to local climate data). Negative influence of the above average January precipitation is particularly hard to explain since we the result for Kruje meteorological station is completely different. Weak correlations with CRU TS 1.2 data set are not a surprise, as we know that precipitation distribution is strongly affected by local conditions, orography, slope, and elevation and 10'x10' can not accurately reproduce local precipitation regimes. Nevertheless, the CRU dataset proved to be a reliable source of climate information, in particular when used as a mean monthly temperature surrogate for a non-existing or erroneous local climate dataset.

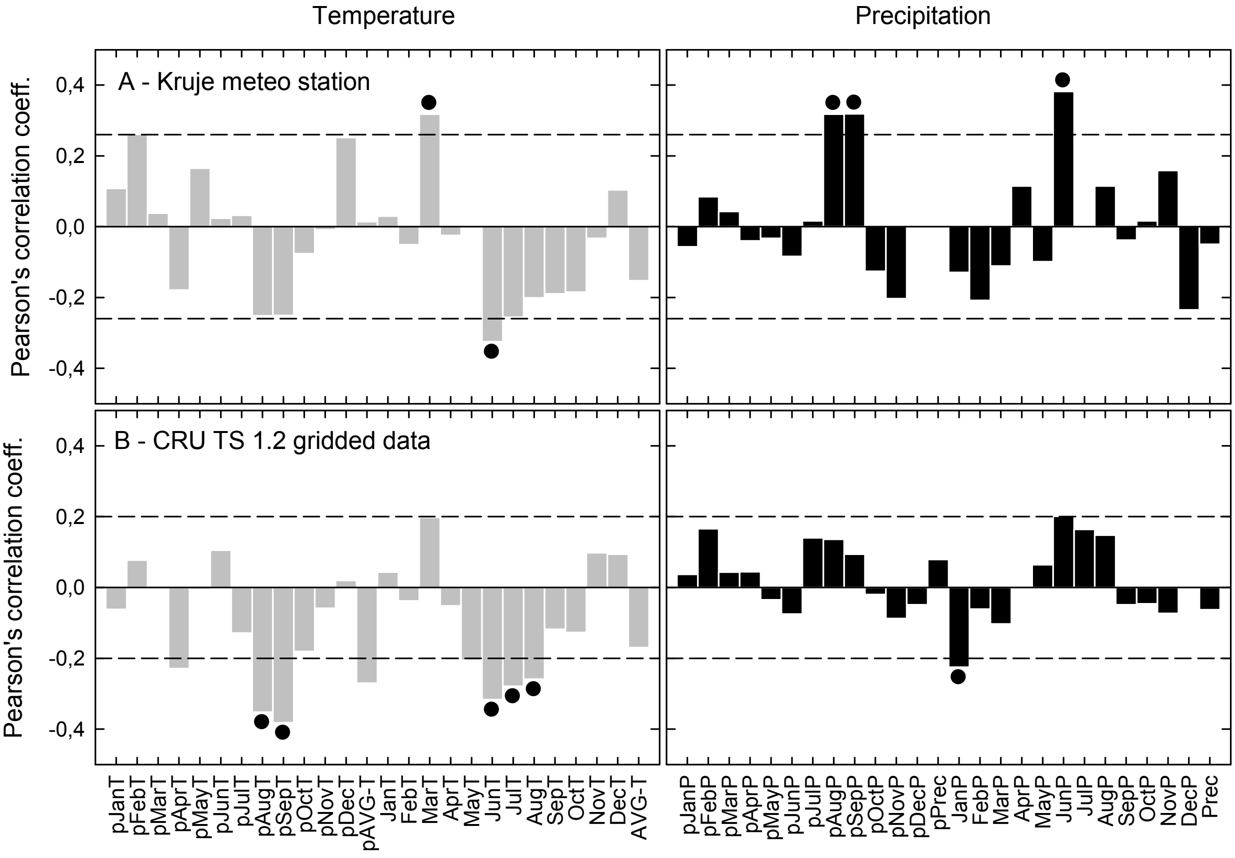

*Figure 3: Simple response to climate conditions - Pearson's correlation coefficients between residual chronology and average monthly temperature and monthly sum of precipitation from local meteorological station Kruje, Albania (top) and CRU gridded data set (bottom). 95% significance level (dashed line) for Kruje climate data is higher because length of available climate data set is shorter than CRU gridded data set. Black circles on the top of the bars show significant correlations.*

## Discussion

We constructed a 238 year long Austrian pine chronology for NE Albania. Chronology was compared with other Austrian pine chronologies from the Balkan peninsula. High statistical values between chronologies from Albania, Bosnia and Herzegovina and Montenegro shows a good regional signal of the Albanian chronology and possibility to be included into a Austrian pine dendrochronological network for the Balkan peninsula.

Response of the Austrian pine chronology to local climate conditions is strong. The highest negative response is between tree-ring indices and average monthly temperature in June. This indicates a reaction to drought stress and lack of water. Influence of the previous year above average temperature in August and September is also negative and significant. This means that above average warmth in autumn (or late summer) is preventing nutrient storage for the next year growing season, which in turn negatively influences xylem ring formation. Oppositely, above average amount of precipitation in previous growing season August and September have a positive influence on the following year xylem ring formation. To achieve a good regional climate response and a better temporal stability of the signal, we need to add more samples from different sites to the current site chronology for Austrian pine in NE Albania. Considering that we found a clear summer drought signal in tree rings, it would probably make sense to produce a PDSI reconstruction rather than just temperature or precipitation reconstruction. This will enable us to produce a long reconstruction of the selected climatic parameters for Albania based on the *Pinus nigra* tree rings.

## Acknowledgements

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# Pointer years in *Picea abies* (L.) Karst. and *Fagus sylvatica* L. tree-ring chronologies from Bulgaria and Romania

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## Introduction

In South-Eastern Europe some of the best-preserved mountain ecosystems in Europe can be found. The Carpathian Mountains in Romania and the Balkan range, Vitosha Mountain, Rila Mountains, Rhodopi Mountains and Pirin Mountains in Bulgaria host centuries-old coniferous and mixed deciduous-coniferous forests. These mountains are the southern and eastern borders of the range of some species. An example is European beech (*Fagus sylvatica* L.). In such locations species demonstrate higher sensitivity to ecological conditions and especially to their extreme variations (Fritts 1976). Due to this fact forests react distinctively to unusual climate and hydrothermal regime. An example is the long drought in the 80-s and early 90-s in Bulgaria and Romania. It was the reason for serious economic problems in the agricultural sector and social stress due to the increasing lack of fresh drinking water (Raev et al. 2003). At the same time it provoked the decline of coniferous afforestations on vast territories and was considered by some researchers as the triggering factor of deteriorating health status of mountain forests.

While such events raise additional discussions on climate, possible climate change and the consequences from it, it is very hard to evaluate such processes due to the lack of long instrumental records of temperatures and precipitation. In this context it is increasingly important to construct reliable high-resolution proxy records and one of the main sources of such are tree rings. Although numerous tree ring chronologies from high elevation or latitude sites in Europe have been used to reconstruct past climate variability (Mann et al. 1999, Briffa et al. 2002, Esper et al. 2002, Mann & Jones 2003, Esper et al. 2005, Büntgen et al. 2006) to this moment only few tree-ring chronologies from South-Eastern Europe are available to the international scientific community (Popa & Kern 2009, Panayotov & Yurukov 2007, 2009). Thus proxy records for this region are even more limited (Xoplaki 2001, Luterbacher & Xoplaki 2003).

The objective of this report is to present and discuss the pointer years in five tree-ring chronologies from the mountains of Bulgaria and Romania and their associations with the climatic conditions. We have selected three chronologies from *Picea abies* (L.) Karst. and two from *Fagus sylvatica* L. They are representative for high mountain locations in the Carpathian Mountains, the Balkan Mountains and Vitosha Mountain.

## Material and methods

The study sites were selected to be representative for subalpine Norway spruce and high mountain Beech sites. We studied one *Picea* site from Vitosha Mountain in Bulgaria (abbreviated "P_BBR"), one from the Southern Carpathians Făgăraş Mountains ("P_BAL") and one from the Eastern Carpathians – Rodna Mountains ("P_LAL") in Romania. The *Fagus* chronologies are from locations in Western Balkan Mountains in Bulgaria ("F_GOV") and Eastern Carpathians (F_COS) (Fig. 1, Tab. 1)

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*Figure 1: Location of the study sites*

*Table 1: Position of study sites*

| Site name | Site ID | Species | Country | Altitude m a.s.l. | Position Lat/Long |
|---|---|---|---|---|---|
| Bistrishko braniste | P_BBR | *Picea abies* | Bulgaria | 1850 | 42º34´ / 23º18´ |
| Balea | P_BAL | *Picea abies* | Romania | 1600 | 45º37´ / 24º36´ |
| Lala | P_LAL | *Picea abies* | Romania | 1650 | 47º31´ / 24º55´ |
| Govezda | F_GOV | *Fagus sylvatica* | Bulgaria | 1500 | 43º13´ / 22º55´ |
| Cosna | F_COS | *Fagus sylvatica* | Romania | 1160 | 47º22´ / 25º02´ |

Tree ring cores were collected at breast height (1.3 m) from dominant trees using an increment borer, mounted on wooden boards, and sanded. We used stem discs from the *Fagus* location in Bulgaria (GOV). Ring widths were measured using incremental measuring tables with accuracy of 0.01 mm. Measured tree-ring width series were visually cross-dated (Stokes and Smiley 1968) and the cross-dating was verified using COFECHA software (Holmes 1983). The series were then standardized with 37% smoothing splines using the ARSTAN software (Cook 1985). In this way we removed the age-related growth trends and preserved the high-frequency climate signal. From these series we calculated the pointer values following the approach of Cropper (1979) with the following equation:

$$Zi = ((x_i - Mw)/SDw)*1000$$

where Zi is the Cropper index; $x_i$ is the standardized tree-ring value for a given year, Mw is mean tree-ring index for the period with which the year is compared and SDw is standard deviation of tree-ring indices for the same period. The length of the period against which each year was compared was 5 years.

As threshold values for detection of pointer years we used values of Zi of +/- 750. Years were considered as common pointer ones for a given chronology if half of the cores displayed pointer years with values above or below the selected threshold.

For the climate analysis we used gridded monthly and seasonal temperature and precipitation fields for the period 1901-2006 from the CRU TS3.0 dataset (Mitchell et al. 2004). To compare our lists of pointer years with climate we performed composite analysis and generated maps using the KNMI Climate Explorer server (Oldenborgh and Burgers 2005; http://climexp.knmi.nl).

## Results and Discussion

Our chronologies cover the last two centuries. We have truncated them in 1800 since our aim is to compare the period covered by most of the series. They consist of 15 to 64 samples and have EPS values above 0.85 in the periods with good replication (Tab. 2)

*Table 2: Statistical and descriptive parameters of the main tree-ring width chronologies. Longer series truncated at 1800.*

| Chronology name and species | Year span | First year | Last year | No. of series | Mean ring width (mm) | EPS above 0.85, year* | Mean sensitivity |
|---|---|---|---|---|---|---|---|
| Bistrishko braniste, *Picea abies* | 135 | 1870 | 2005 | 64 | 1.25 | 1870 | 0.23 |
| Balea , *Picea abies* | 204 | 1800 | 2004 | 40 | 1.85 | 1800 | 0.17 |
| Lala , *Picea abies* | 203 | 1800 | 2003 | 40 | 1.66 | 1800 | 0.19 |
| Govezda, *Fagus sylvatica* | 302 | 1701 | 2002 | 15 | 1.23 | 1900 | 0.38 |
| *Cosna, Fagus sylvatica* | 206 | 1800 | 2006 | 20 | 1.38 | 1840 | 0.38 |

* The year displays the moment from which the EPS values are higher than 0.85. If this threshold was reached at later period than the beginning of the chronology, the year is the central one for the 50-year period over which the EPS was calculated.

Pointer years, which coincided in at least two *Picea abies* chronologies, were 1853, 1862, 1876, 1913, 1927, 1929, 1933, 1938, 1940, 1943, 1945, 1946, 1949, 1962, 1964, 1989 and 2001.

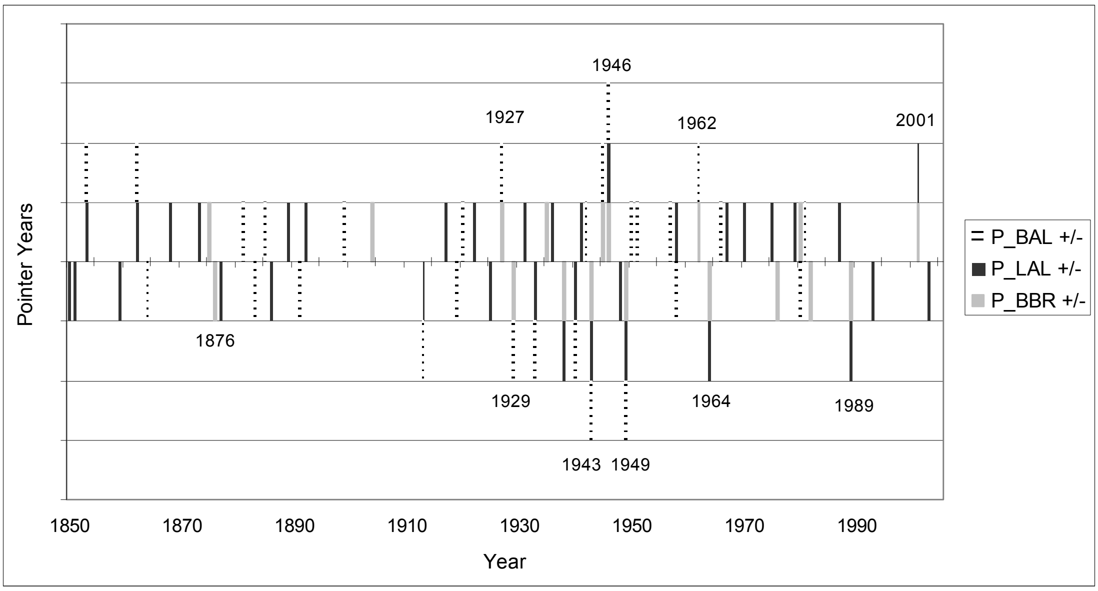


*Figure 2: Pointer years in Picea abies chronologies from subalpine locations from Bulgaria (P_BBR) and Romania (P_LAL and P_BAL). Bars display presence of a specific pointer year in a chronology.*

Of them common between Bulgaria and at least one site in Romania were 1876, 1929, 1943, 1948-49, 1964 and 1989. Out of those positive pointer years were 1927, 1945-46, 1962 and 2001 (Fig.2).

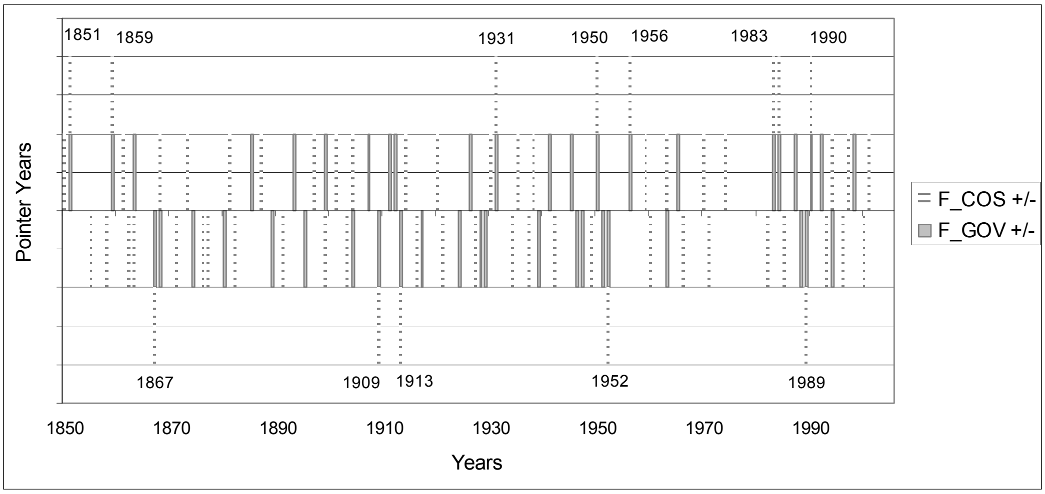


*Figure 3: Pointer years in Fagus sylvatica chronologies from high mountain locations from Bulgaria (F_GOV) and Romania (F_COS). Bars display presence of a specific pointer year in a chronology.*

Our composite analysis shows that common negative *Picea abies* pointer years are associated with climate situations with colder summers, but also with drier winters and early summer periods. Coinciding positive years are related to warmer than average July and August (Fig. 4).

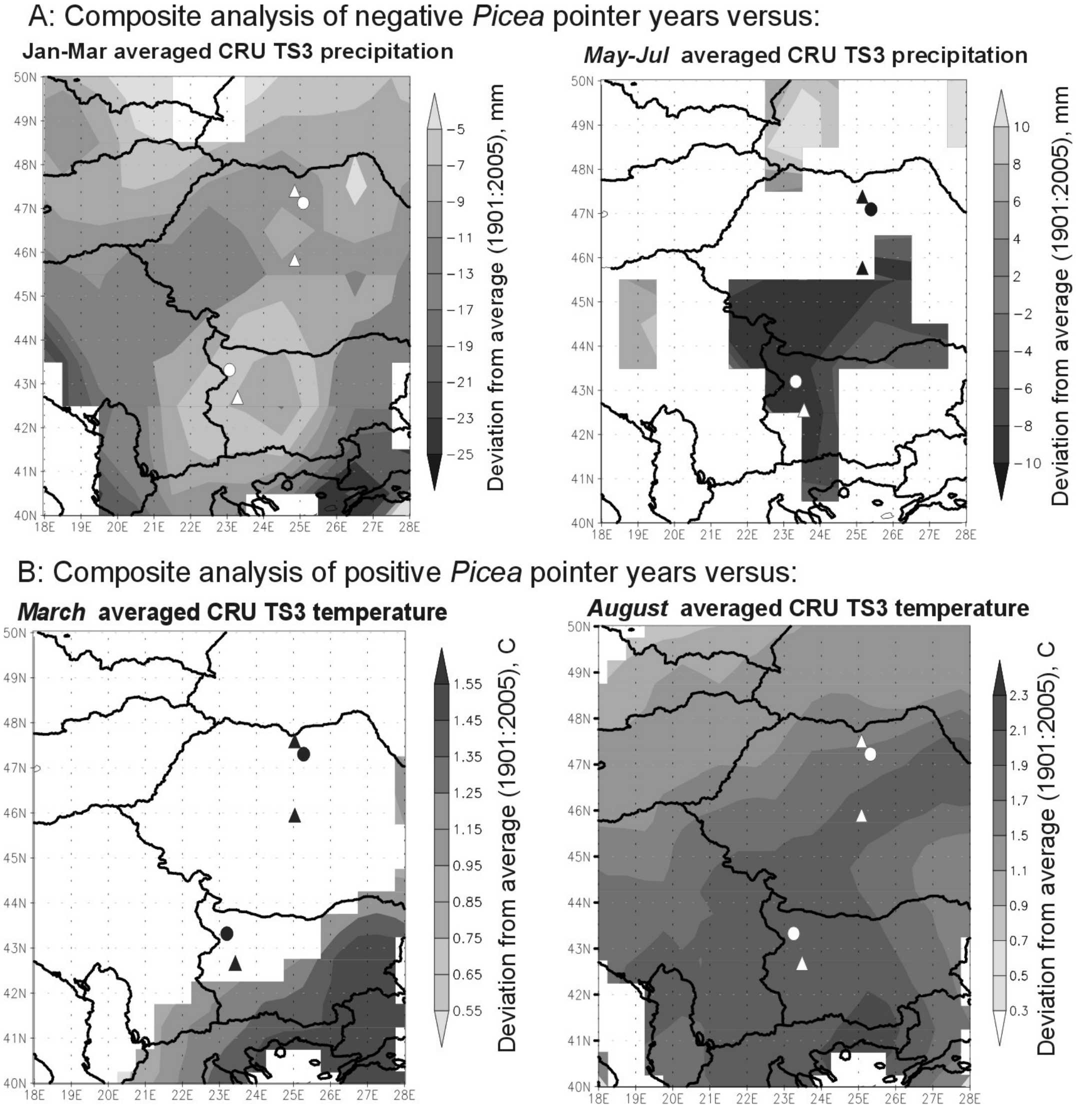
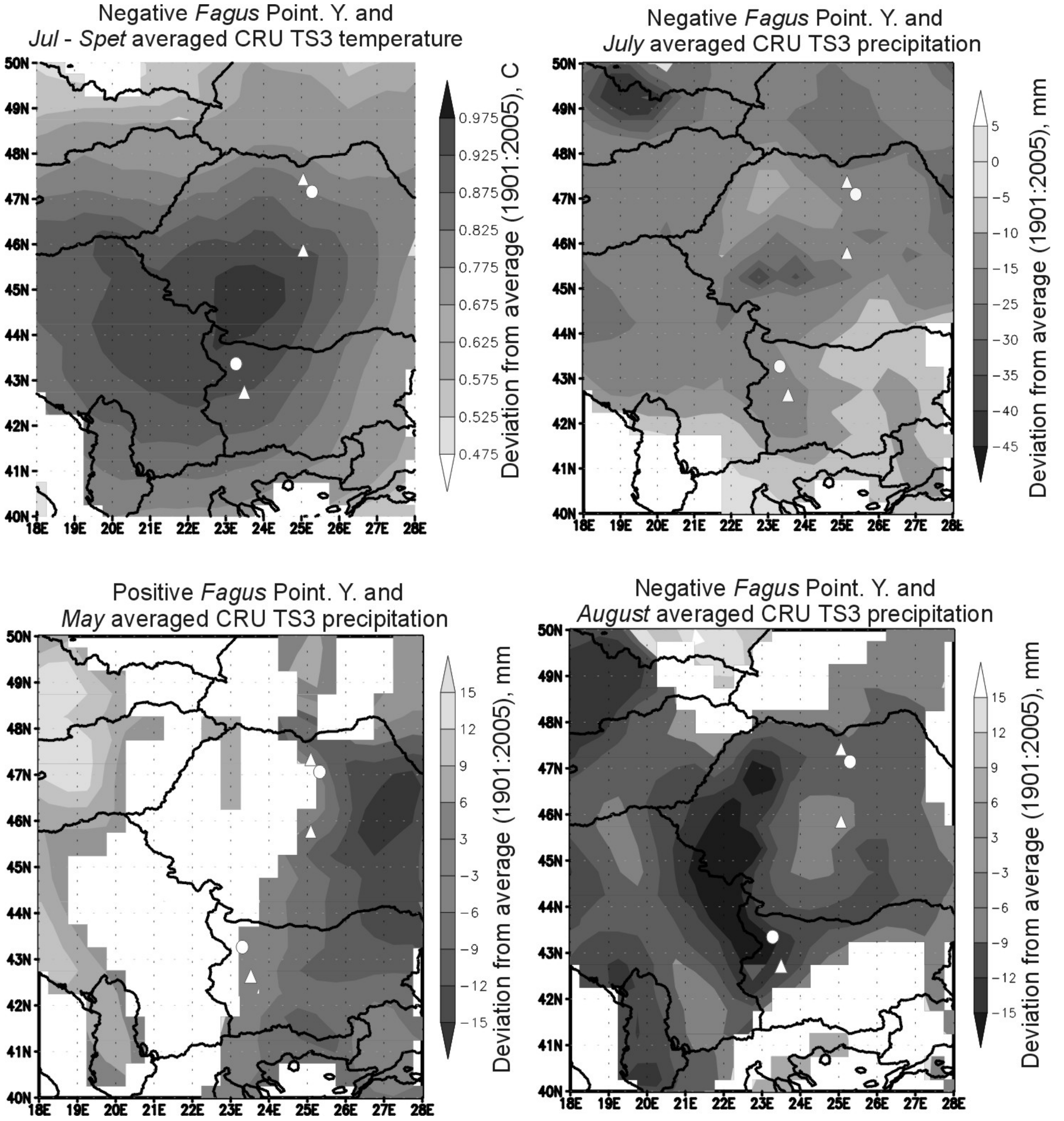


*Figure 4: Composite analysis of Picea abies pointer years. Gray shading displays significant deviations from the average values.*

Since our *Picea abies* chronologies are from subalpine locations and thus are subjected to lower temperatures and shorter duration of the vegetation period, the finding that some of the negative pointer years were associated with colder than usual summers is expected. Such results have been received in the analysis of other tree-ring series from that species in Europe (Neuwirth et al. 2007, Buntgen et al. 2006). It is also known that the growth of trees close to treeline is limited mainly by low summer temperatures (Tranquillini 1979, Korner 1998). More surprising result is that drier winters and early summer periods can also be the reason for negative pointer years. A possible explanation is that decreased snowfalls and early-summer precipitation may cause unavailability of the needed quantities of moisture at the period when cell division is most active. Detailed studies of the processes of tree ring formation have shown that June is the month with most active tracheid formation at treeline locations (Rossi et al. 2006). Therefore we consider that a drought-type stress at that period could cause production of narrower earlywood and thus tree rings. In our *Picea abies* site in Bulgaria some of the trees are growing on shallower soils formed on large spherical rock blocks, which can be the reason for draining of the soil profile in cases with extended periods without sufficient moisture supplies by snowfalls or rains.



Negative *Fagus* Point. Y. and *Jul - Spet* averaged CRU TS3 temperature

Negative *Fagus* Point. Y. and *July* averaged CRU TS3 precipitation

Positive *Fagus* Point. Y. and *May* averaged CRU TS3 precipitation

Negative *Fagus* Point. Y. and *August* averaged CRU TS3 precipitation

*Figure 5: Composite analysis of Fagus sylvatica pointer years. Gray shading displays significant deviations from the average values.*

Common pointer years in Bulgarian high-mountain (1500 m a.s.l) *Fagus sylvatica* chronologies were 1867, 1909, 1913, 1952, 1989 (negative) and 1851, 1858, 1931, 1950, 1956, 1983-84 and 1990 (positive). For the Romanian mountain beech site the negative years were 1851, 1859, 1931, 1950, 1956, 1983 and 1990 (Fig. 3). Some of the negative years between Romanian and Bulgarian mountain sites were not common. A possible explanation of that fact we can be found in the specifics of the stands: in Bulgarian case - pure common beech forest; in Romania - mixed beech, spruce and fir forest. We assume that mixed forest create their own local climate conditions which are less sensitive to the global climate conditions shown in (Fig. 5). The divergence from Bulgarian pointer years could be combination not only of local-global climate influence but also combination of some additional factors as internal competition between different species in the mixed forest. Some of the negative pointer years (e.g. in the Romanian chronology) can be explained by beech fruiting (Kern & Popa 2007). The negative pointer years in the Bulgarian beech stand are result mainly of the higher than usual temperatures and lower precipitation during summer months (Fig. 5). Positive were associated with drier and thus warmer late-spring period, which contributes to earlier growth period start. Our results are in consonance with the results shown in one case study for the West Balkan Range Mountain (Dimitrov et al. 2003) and the results for the Central Apennini site (Piovesan et al. 2003). Namely, pure common beech stands suffer from the summer drought. The negative pointer years (in some cases missing rings) appear after extreme low level of precipitation during the months June, July and August combined with extremely high temperatures for the same period of the year. In opposite – positive pointer years are result of the wet summers which made possible elongation of the vegetation period.

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# Climate signals in stable isotopes of Juniper from Turkey back to AD 1025

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## Introduction

Turkey is located in the eastern Mediterranean which experiences repeatedly extreme and persistent drought and heat episodes. Water availability is an increasingly sensitive topic in the region which faces growing human populations and limited water supplies at the same time (Türkeş 1998). To comprehend the natural hydrological variability is of great importance as it will help to find a sustainable management of regional water resources.

The study of pre-instrumental time periods allows the recognition of climate cycles and patterns on long time scales that are not clearly observable over the limited length of time of available instrumental records. However, understanding these long-term climatic variations is important if future climate changes are to be accurately predicted (Jones et al. 2006).

A most suitable help to this dilemma are offered by natural archives such as tree rings which can capture information about climate variability on longer time scales. Although several dendroclimatological studies have been conducted (D'Arrigo & Cullen 2001, Touchan et al. 2003, Akkemik & Aras 2005, Touchan et al. 2005, Touchan et al. 2007, Akkemik et al. 2008), dendroisotopic studies in Turkey are still lacking. Here we present the latest results of an ongoing project studying the long-term variations of carbon and oxygen stable isotopes derived from tree rings of *Juniperus excelsa* M. Bieb. trees from a site near Antalya, Turkey.

## Material and Methods

The study site Jsibeli, situated near Elmali in the Antalya district experiences Mediterranean climate characterised by dry, hot summers and cool, rainy winters with a total annual rainfall of approximately 750mm. The site (1853-2022m a.s.l.) is covered with snow from December to April (Türkeş et al. 2002). From a sample pool of 54 cores and 14 stem disc samples seven trees (15 cores of five living trees and two cross-sections cut from stumps) were chosen for further isotope analysis (Touchan et al. 2007). The selection criteria for the samples were a high correlation with the ring-width site chronology, smallest possible numbers of missing rings, no tree-ring sequences with ring widths below 0.1mm, no significant growth suppressions and releases and no scars, reaction wood or other wound reactions. The individual tree rings were first separated with a scalpel. Cellulose was then extracted following standard procedures (*e.g.*, Helle & Schleser 2004) and burned to $CO_2$ or pyrolised to CO for mass spectrometer analysis of $\delta^{13}C$ or $\delta^{18}O$, respectively. $\delta^{13}C$ values are expressed as deviations from the Vienna Pee Dee Belemnite (VPDB) standard and $\delta^{18}O$ values as deviations from the Vienna Standard Mean Ocean Water (VSMOW) standard (Mook 2001). Carbon isotope records were corrected for the decrease of atmospheric $\delta^{13}C$ values due to fossil fuel burning since the beginning of industrialisation AD 1850 (Friedli et al. 1986, Francey et al. 1999, Leuenberger 2007).

The $\delta^{13}C$ and $\delta^{18}O$ site chronologies were then correlated with monthly, seasonal and annual climate data, i.e., precipitation, temperature and the self-calibrating Palmer Drought Severity Index (scPDSI) from the meteorological station Elmali (data available fort he time period 2000 to 1960), located near the study site, using Pearson's simple correlation coefficient. The dominant climatic forcing factors controlling tree growth were calibrated against the site tree-ring isotope chronologies. The climate record was split into two equally long periods. The first period is used for calibration and the second for the independent verification of the data (see Heinrich et al. 2009 for details). The ordinary least square method was applied to find the best regression model which was then used as the transfer function (Fritts 1976). The Pearson's correlation coefficient between instrumental and reconstructed values was computed to estimate the ability of the tree-ring data to predict the selected climate factors. The verified simple linear regression model was then used to reconstruct climate for the site. Spatial correlation analyses were conducted in the KNMI climate explorer (van Oldenborgh 1999).

## Results and Discussion

The $\delta^{13}C_{CorrA}$ series corrected for the decrease of atmospheric $\delta^{13}C$ values and the $\delta^{18}O$ series cover the period AD1025 to 2006. It needs to be made clear that the analysis of the samples for $\delta^{13}C$ and $\delta^{18}O$ isotopes is still ongoing and therefore the mean series are preliminary. The mean $\delta^{13}C_{CorrA}$ chronology exhibits relatively low values in the period AD1025 to the mid 16th century followed by relatively higher values until the 20th century. The $\delta^{18}O$ series does not contain such a long-term trend as the $\delta^{13}C_{CorrA}$ series but shows more high-frequency variability (Fig. 1).

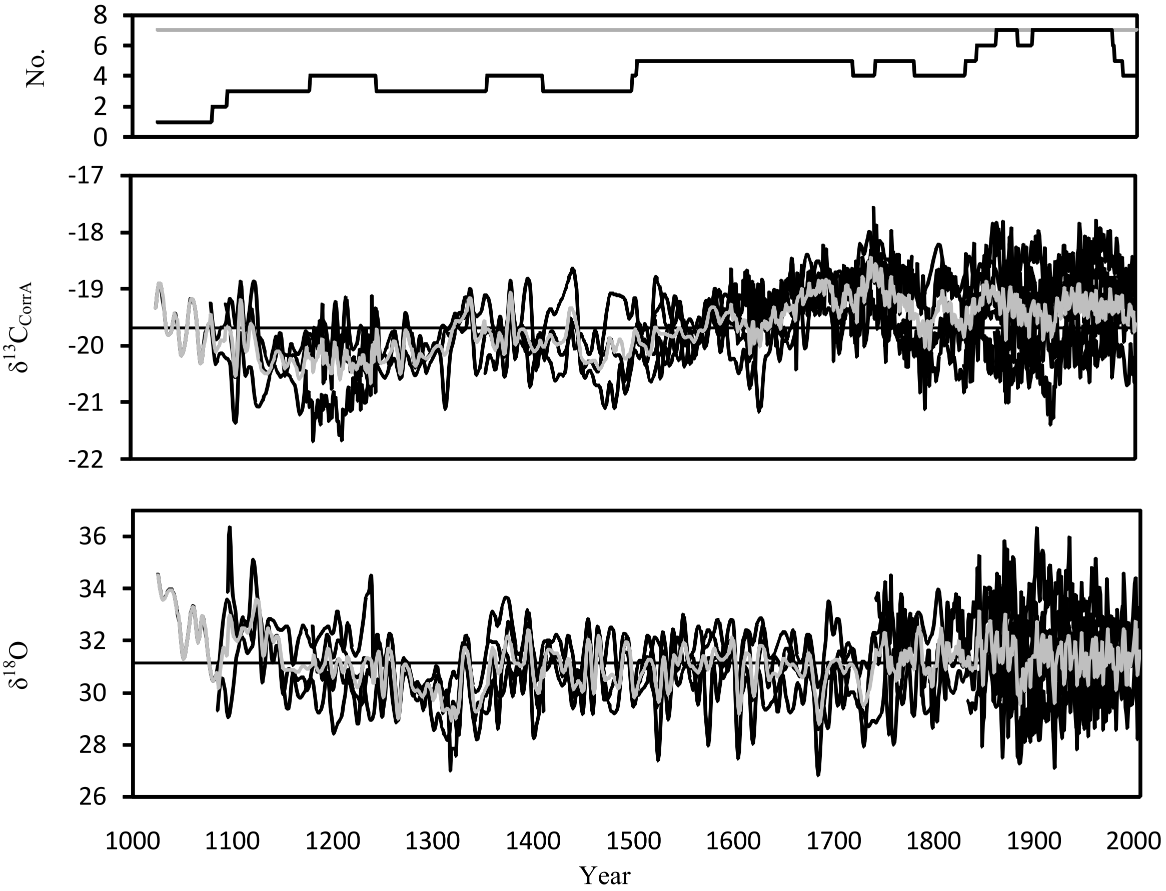

*Figure 1: Current sample depth (black graph) and planned sample depth (grey graph) (top), corrected $\delta^{13}C$ series (mid), $\delta^{18}O$ series (bottom), grey graphs = series means.*

The tree-ring statistics of the $\delta^{13}C_{CorrA}$ (rbar=0.48 / EPS=0.86) and $\delta^{18}O$ series (rbar=0.44 / EPS=0.85) statistics imply a good quality of the mean chronologies and suggest that they are suitable for further dendroclimatic research.

The climate response plots presented in Heinrich et al. (2009) indicated highly significant negative correlations between $\delta^{13}C_{CorrA}$ and January to May temperature and between $\delta^{18}O$ and precipitation of April to July, respectively. This lead us to the assumptions of a distinct winter to spring temperature signal and a summer precipitation signal, recorded in the isotope records.

Furthermore, the distinct summer precipitation signal was also reflected in the significant correlation between scPDSI and the $\delta^{18}O$ series, in particular, for the period May to July. Overall, the strong hydrological signals in the isotope chronologies corroborate results by Touchan et al. (2007). Based on the established climate growth relationship we here present preliminary reconstructions of Jan-May temperature (Fig. 2) and summer scPDSI (Fig. 3).

The temperature reconstruction (Fig. 2) exhibits long-term trends. The most obvious trend is the difference between the periods before and after the 16th century. Before the 16th century the temperature is mostly above the long-term average while after the 16th century it stays mainly below this average. However, it needs to kept in mind that the reconstruction is still of preliminary character, and therefore it cannot be ruled out that the sample depth, changing in time, might have an impact on the long-term trend. Artificial trends may be produced when new trees are entering the chronology, as is the case in the 16th and 17th centuries. Therefore, concluding statements about long-term climate trends can only be drawn from the final chronologies. The medieval warm period (MWP) is reflected by temperatures staying constantly above the average between the early 12th and mid 14th century. The little ice age (LIA) heralds itself with a first plummet of the reconstructed temperatures in the outgoing 16th century and the LIA is in full swing during the 17th and 18th centuries, as indicted by the low values of the reconstruction. Between the 17th and 19th century three extreme temperature lows are discernible, that is, the first during the late 17th century, the second in the mid 18th century and the third in the mid 19th century. These minima are generally agreed on and have been found elsewhere (Grove 1988).

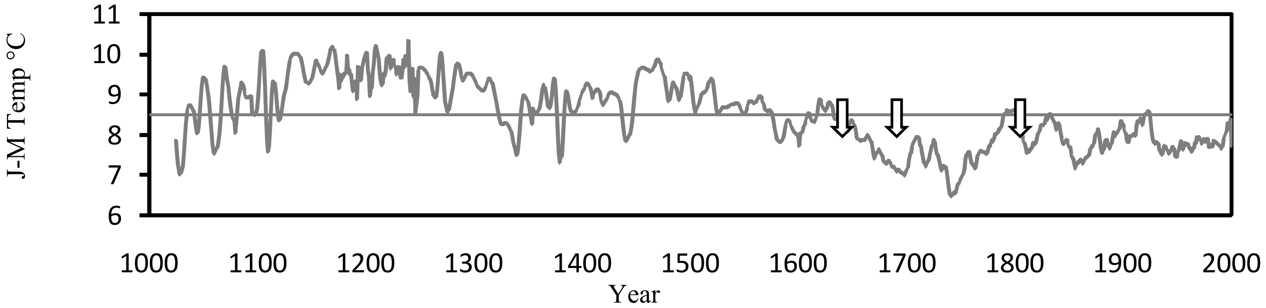

*Figure 2: Preliminary reconstruction of Jan-May Temp based on* $\delta^{13}C_{CorrA}$*, arrows indicate two minima of the LIA*

The preliminary reconstruction of the summer scPDSI (Fig. 3) contains less long-term oscillations than the temperature reconstruction. The impacts of the MWP and LIA seem to be less obvious in figure 3, however, a trend to more dry conditions during the MWP, indicated by frequent below-average values of the scPDSI during the period mid-12th century to early 14th century, is discernible nevertheless. In comparison to the reconstructed May to June precipitation record from Elmali which is based on tree-ring widths series (Touchan et al. 2007), our reconstruction of the summer drought index shows some similar trends. For example, the record by Touchan et al (2007) identifies the later part of the 16th century as the wettest period of the last 900 years which is confirmed by our reconstruction. However, ultimate conclusions should only be drawn from our final chronology.

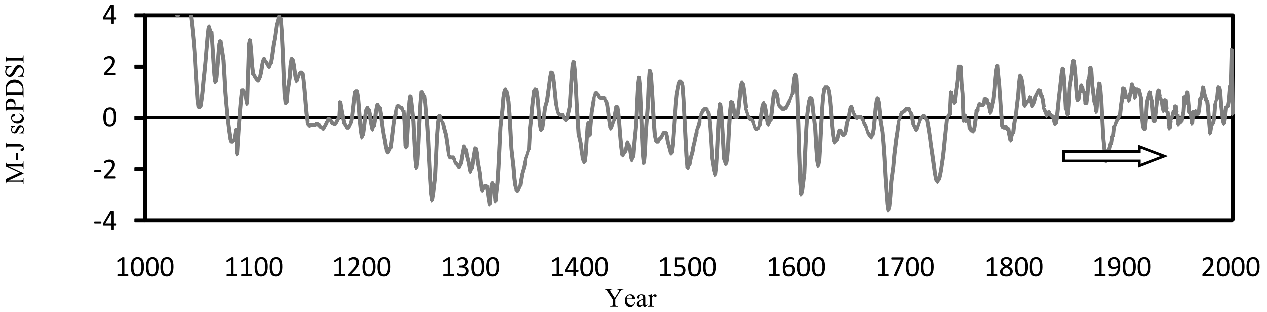

*Figure 3: Preliminary reconstruction of summer scPDSI based on* $\delta^{18}O$*, arrow indicates the wetter period in the 20th century*

Another remarkable trend in figure 3 is visible towards the end of the series. After a last substantial swing below the line of the long-term average in the late 19th century the reconstructed scPDSI stays near or above this line during the entire 20th century. From this pattern it can be derived that the 20th century was one of the wettest centuries in the last 1000 years at the study site.
Such trends to more humid conditions have been found in other tree-ring proxy-reconstructions (China: Sheppard et al. 2004, Karakorum: Treydte et al. 2006, SW-Asia: Anderson et al. 2002, S-Germany: Wilson et al. 2005) as well. It is an interesting fact that, despite global warming, all these sites seem to indicate wetter conditions during the last century. The results urge for more long chronologies sensitive to precipitation to confirm this trend elsewhere as well, especially from the more arid zones of the planet because here water is crucial and thus a politically sensitive resource (Jones et al. 2006).

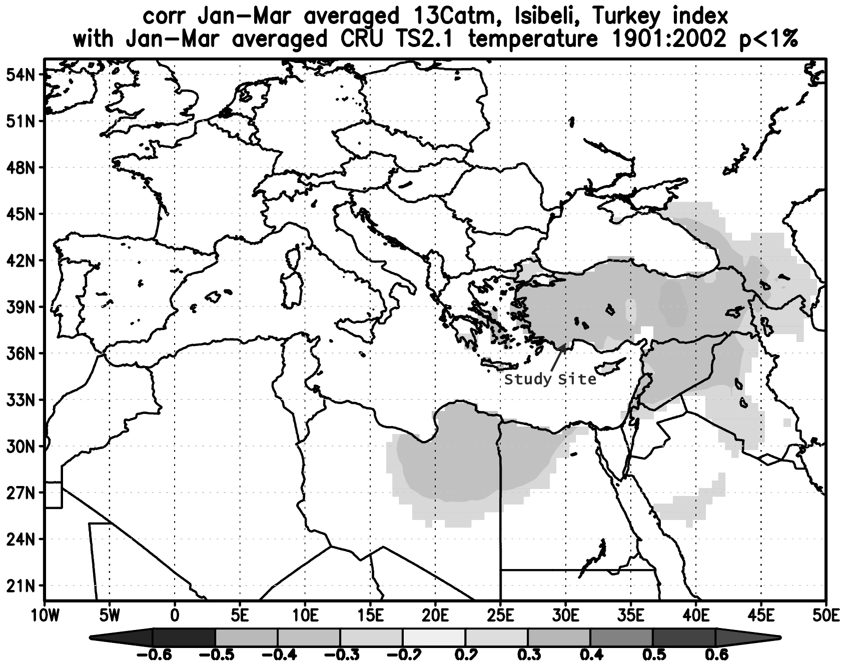

*Figure 4: Spatial field correlations (van Oldenborgh 1999) between mean Jan-May temperature and* $\delta^{13}C_{CorrA}$*, arrow indicates location of the study site*

In a next step, the spatial field correlation (van Oldenborgh 1999) between the mean Jan-May temperatures and $\delta^{13}C_{CorrA}$ were computed (Fig. 4). The map demonstrates that the correlation between the $\delta^{13}C_{CorrA}$ chronology and the mean Jan-May temperature covers an area of most of Turkey, Syria and northeast Africa. Intriguingly, most of the field correlation is oriented towards the south and east of the study site but no spatial correlation with Europe is indicated.

Most of the available proxydata are derived from sample locations in Central Europe (e.g., Jones et al. 2009). In contrast, only a few records have been developed for the Middle East so far (Touchan et al. 2005). Consequently, the east- and southward directed correlation patterns indicate an important potential for additional palaeoclimate reconstructions in the Middle East.

In order to investigate whether this limited spatial association is because proxy data instead of meteorological data were used, spatial field correlations were computed between the monthly temperatures of Elmali Station (SW-Turkey) and the monthly temperatures of the rest of the old world (Fig. 5). It is important to note that the colours indicate negative correlations in figure 4 and mainly positive correlations in figure. 5. This is because in figure 4 the $\delta^{13}C_{CorrA}$ chronology with its negative values is correlated with temperatures while in figure 5 temperatures from Elmali Station (SW-Turkey) are correlated with temperatures of the rest of the old world. The separation into monthly field correlations (Fig. 5) reveals temporal and spatial instabilities between temperatures from Elmali and the rest of the old world. In most months the correlation patterns shown in figure. 4 can also be found in figure 5, but in some months, significant positive and negative correlations between temperatures from Elmali and different regions in Western Europe appear temporarily. Significant negative correlation fields can be found for Scandinavia in January, February, October and December and for the Iberian Peninsula and parts of Central Europe in March, April, July and October. Hence, the spatial correlation fields for the meteorological records of Elmali and the rest of the Old World support the results of the previous analysis that there seems to be no common stable variance between the Mediterranean climate of Turkey and that of other south European countries such as Spain or Italy.

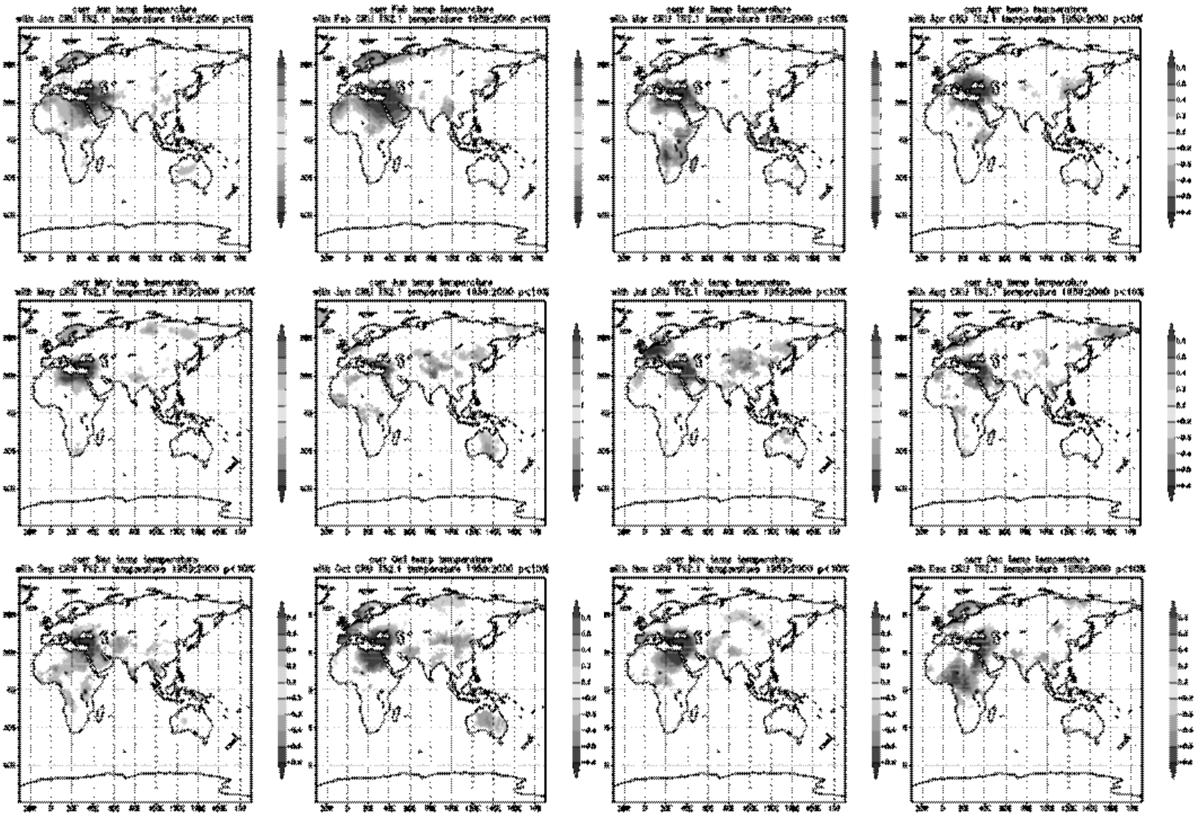

*Figure 5: Spatial field correlations (van Oldenborgh 1999) between monthly temperatures of Elmali Station (SW-Turkey) and the rest of the old world (top from left to right: January to April, middle from left to right: May to August, bottom from left to right: September to December)*

One possible explanation for this lack of spatial correlation with the western Mediterranean is the existence of the Mediterranean Oscillation Index (MOI) (Conte et al. 1989). The MOI is defined as the normalised pressure difference between Algiers and Cairo. This means that favourable circulations for high temperatures in the East are opposite to favourable circulations for high temperatures in the West and vice versa, which results in a so-called seesaw effect. However, the field correlations presented here indicate that the MOI influences the correlation between East and West only in some months and therefore it may be concluded that the same holds true for the field correlations between our $\delta^{13}C_{CorrA}$ proxydata and the Jan-May temperatures as shown in figure 4. The results urge for further research which needs to produce a Mediterranean network of climate-sensitive isotope proxies shedding more light on the temporal and spatial correlation instabilities identified here.

## Conclusions

In conclusion, it has been established that $\delta^{13}C$ and $\delta^{18}O$ in tree rings are useful proxies to reconstruct climate in Turkey and that they have good potential for further palaeoclimatological reconstructions. Different tree-ring parameters contain different climatic signals. The preliminary reconstructions suggest that during the last 100 years Southwest-Turkey has experienced wetter summers and also that there is a long-term trend towards lower spring temperatures. Furthermore, the effects of the MWP and LIA can also be found in the $\delta^{13}C_{CorrA}$ based temperature reconstruction. Finally, temporal and spatial correlation instabilities were identified in the proxy data as well as the meteorological data sets. The nature of these instabilities deserves more attention by producing more high quality proxy data sets from other sites throughout the Mediterranean region which could then be used to model the long-term relationship between the different parts of the Mediterranean region, e.g., East and West.

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# Development of south Swedish pine chronologies from peat bogs – extension of existing records and assessment of palaeoclimatic potential

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## Introduction

Ongoing and future climate change is a crucial issue for society and requires deeper understanding of the climate system and natural climate variability. Improved methods together with more accurate radiometric dating have led to the development of refined and more detailed climate reconstructions and highly valuable knowledge of Holocene climate variability and its forcing mechanisms (Mayewski et al. 2004).

Tree-rings have proved to be a valuable source in paleoclimatic research (Fritts 1976, Schweingruber 1988, Cook & Kairiukstis 1990). Trees growing at or close to their distribution limits normally produce tree-rings which provide climate information with annual resolution (Cook & Kairiukstis 1990). Climate change can cause hydrological variations and fluctuations of the groundwater table that can be recorded in e.g. peat deposits. Periods of relatively warm and dry climatic conditions sometimes allow pine establishment on peat bogs. Tree growth on peatlands depends mainly on depth and fluctuation of the local water table (Linderholm et al. 2002). High water tables may depress growth, as nutrients become less available in poorly aerated soil (Mitchell & Ryan, 1997). Water table depth is regulated by seasonal and annual variations in temperature and precipitation.

Dendroclimatic studies of sub-fossil wood in mid- and northern Sweden have been performed by e.g. Gunnarson (1999), Grudd et al. (2000), Grudd (2008), Linderholm (2001) and Linderholm et al. (2002). However, it has been shown that tree-ring records from these regions are more suitable for studies of temperature change (Linderholm et al. 2002). Whereas temperature as well as precipitation influence growth rates of peatland pines, trees growing on bogs in southern Sweden are more sensitive to humidity variations than trees in the north (Linderholm et al. 2002) and might therefore be more suitable for studies of past humidity variations. Besides, it is of great interest to extend existing pine chronologies from southern Sweden maintained at the Swedish National Laboratory for Wood Anatomy and Dendrochronology, which at present reach back to approximately AD 900. New chronologies may also fill temporal gaps between previously obtained floating bog-pine chronologies (Edvardsson 2006).

Here I present two new south Swedish chronologies based on tree-ring width (TRW) from Scots pine (*Pinus sylvestris*) covering the periods c. 5235-4590 BC and 2172-1204 BC and discuss potentials and problems of using peatland trees as climate indicators.

## Data and Methods

### *Research area*

Since the last deglaciation, large areas of Sweden have become covered by peatlands on which tress established during favourable climate periods. In this study two south Swedish peat bogs used for peat-mining have been investigated (Fig. 1A): Viss mosse (55°51´N, 13°49´ E) and Åbuamossen (56°19´ N, 13°55´ E).

Bogs used for peat-mining are targeted in this study since they provide sufficiently large amounts of peatland trees to overcome problems related to suppressed growth and initially unknown age

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distributions. Wood remains in bogs normally appear in horizontal layers called *stump horizons* (Fig. 1B). 80 and 128 trees, each with at least 80 annual rings, were collected during fieldwork at the two study sites, respectively.

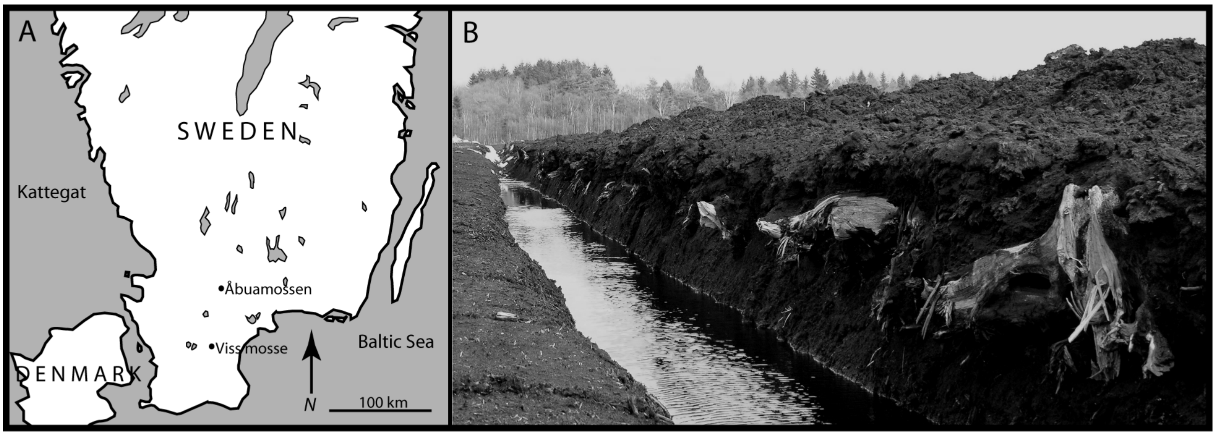

*Figure 1: A) Location of the studied peat bogs, Viss mosse and Åbuamossen, southern Sweden. B) A drainage ditch at Viss mosse with a stump horizon. The sub-fossil pine material is from a forest that established on the bog at c. 5200 BC.*

### *Measurements and data analysis*

Ring widths of each sample were measured with a precision of 0.01 mm, using standard dendrochronological equipment (Schweingruber 1988). At least two radii from each sample were measured to increase the representativity of the data. Measurements were performed using CATRAS software (Aniol 1988). Assessments of the cross-dating and measurement quality, as well as the strength of the master chronologies, were performed with the software COFECHA (Holmes 1983).

Standardization is a data transformation which minimises non-climatic ring-width variations related to age and geometry (Fritts 1976). The influence of local endogenous and standwide exogenous disturbances on ring width variations can often be reduced if sampling of obviously disturbed trees is avoided during fieldwork and if large numbers of samples are collected. Most often, raw ring-width series show a decreasing age-related trend. A useful model for this age trend is the modified negative exponential curve (Cook & Peters 1997). However, the measured material often shows periods with extremely narrow rings during both the first and last decades of growth. Therefore, a more flexible standardization method was applied. Thus, the ring-width series were standardized with a 67% spline with the software ARSTAN (Holmes et al. 1986).

### *Radiometric dating*

Precise calendar ages cannot be determined by cross-dating the south Swedish bog-pine chronologies or included individual samples with available reference chronologies. However, the tree-ring series obtained can be assigned on a rigid, but floating timescale with annual resolution. An approximate calendar age for the chronologies can be obtained by radiocarbon dating of tree-rings from one or several included samples.

The use of wiggle-match dating (WMD) makes it possible to improve the accuracy of radiocarbon age determinations and to provide more accurate dating of the chronologies (Blaauw et al. 2003). The WMD method is based on the non-linear relationship between radiocarbon and calendar ages by fitting a sequence of radiocarbon dates with known intervals between them on the radiocarbon calibration curve. Intervals which make it possible to tie different radiocarbon dates to more narrow sequences on the calibration curve are determined by counting the exact number of annual tree-rings between different radiocarbon-dated annual rings. The calibration and wiggle matching was made using defined sequence tests in the program OxCal v4.0 (Bronk Ramsey 2007) based on the IntCal04 radiocarbon calibration curve (Reimer et al. 2004). The ages used for the dated chronologies are the calculated mean values (µ) from the defined sequence probability curves, and the margins of error are the uncertainties at the 68.2% probability level after wiggle matching.

## Results

### *Chronologies*

In total, 80 *in situ* samples were collected at Viss mosse and 44 of these samples were used to develop a 646-year chronology (Fig. 2). The cross-match of the remaining 36 samples was either too weak or non-existing. This was most likely due to anomalous growth conditions or separate age distributions. Six samples from the chronology were dated by radiocarbon wiggle matching to give the chronology an age as accurate as possible. The age interval of the Viss mosse chronology after WMD is 5235-4590±19 BC. Years and events with suppressed growth were determined for the period with an expressed population signal (EPS) above 0.75, which correspond to periods containing at least four overlapping samples (in total 520 of the 646 years). The longest observed period of suppressed growth covers six years, while the longest period with elevated growth is eight years.

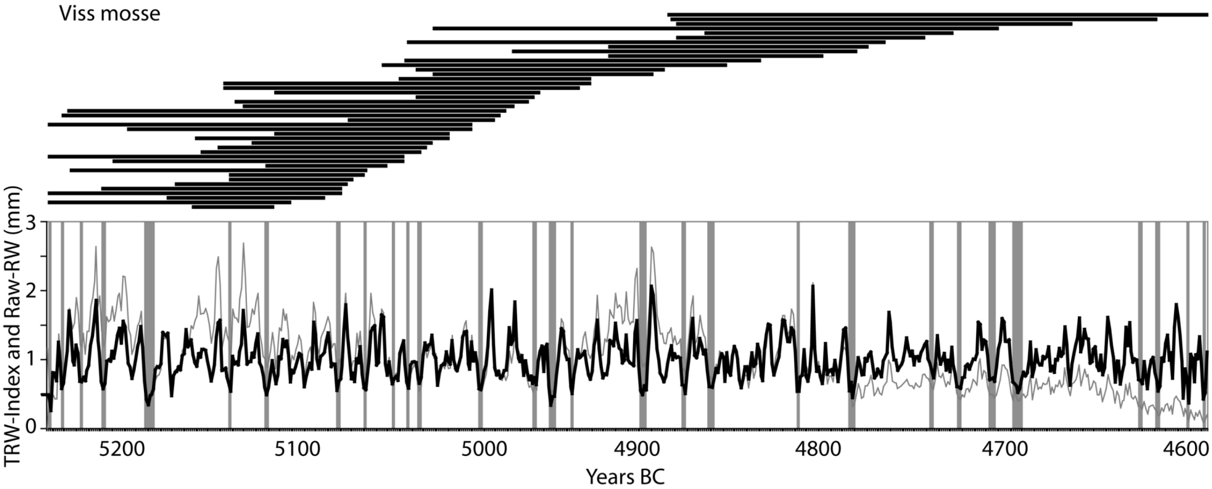

*Figure 2: 646-year Scots pine chronology from Viss mosse. The thick black curve is the standardized chronology (indices), while the thin grey curve shows raw ring-width measurements (mm). The black lines show the overlap between individual TRW series. Periods of two or more years with suppressed growth are highlighted with grey bands.*

At Åbuamossen, 98 from totally collected 128 samples were used to develop a 969-year chronology (Fig. 3). Seven samples from the chronology were dated by radiocarbon wiggle matching. All samples fit on the IntCal04 curve (Reimer et al. 2004) at the 95.4% probability level, and just one sample does not fit on the curve at the more narrow 68.2% level. The age interval and margin of error is 2172-1204±9 BC at the 68.2% probability level. EPS is above 0.75 during 754 of the 969 years. The longest period of suppressed growth at Åbuamossen covers 19 years.

The average ring width of the samples included in the Viss mosse chronology is 1.0 mm, while the material from Åbuamossen has an average TRW of 0.9 mm. Narrow tree rings like this may result from generally unfavourable growing conditions in highly acidic environments, from a high water table, and in some cases from over-mature trees.

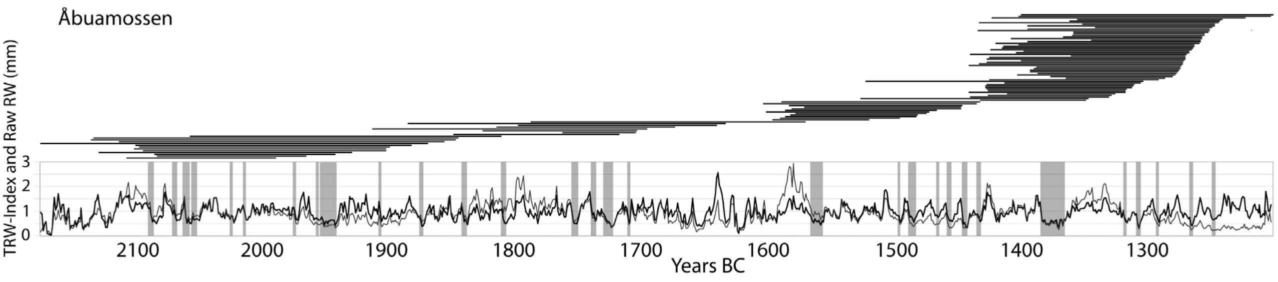

*Figure 3: 969-year Scots pine chronology from Åbuamossen. The thick black curve is the standardized chronology (indices), while the thin grey curve shows the raw ring-width measurements (mm). The black lines show the overlap between each individual TRW series. Periods of two or more years with suppressed growth are highlighted with grey bands.*

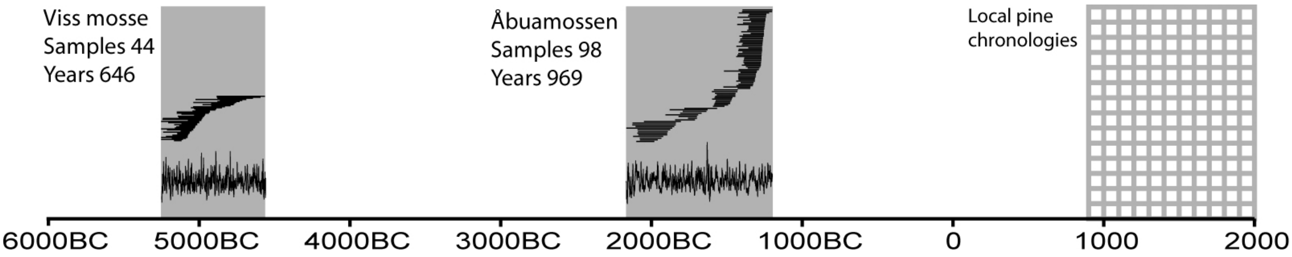

*Figure 4: Together the chronologies from Viss mosse and Åbuamossen cover 1615 years. A third, yet undated chronology will probably fill 1112 years of the gap in between the two chronologies, but large amounts of material is needed before it is possible to connect the records with any existing pine chronologies from the region (period between 900 AD and present, marked with check pattern).*

## Discussion

### *Peatland trees as climate indicators*

Scots pine is normally a pioneer species which rapidly invades open and exposed sites after disturbances like drainage, deforestation, fire or insect invasion (Freléchoux et al. 2000). However, growth dynamics of trees growing on peat bogs may differ from those on solid ground. Tree growth on peatlands is highly dependent on the depth and variability of the water table beneath the root system (Boggie 1972, Freléchoux et al. 2000, Vitas & Erlickytë 2007, Eckstein 2009). High groundwater tables generate unfavourable growth conditions as a result of several physical, chemical, and biological processes (Boggie 1972, Vitas & Erlickytë 2007). Together these factors result in an environment where tree growth is strongly inhibited by lack of oxygen, accumulation of $CO_2$, reduction of Fe and Mn, formation of toxic compounds and by anaerobic decomposition (Vitas & Erlickytë 2007). A groundwater rise would result in less peat volume from which the roots can extract nutrients (Linderholm 2001). It is a slow and complicated process for trees to establish solid root systems in deep peat. Deep root systems are essential to ensure stability, but trees growing in places where the water table is close to the surface develop almost completely lateral root systems (Boogie 1972, Eckstein 2009).

A groundwater lowering on a peatland can trigger stronger growth or an invasion of trees. Increased amounts of precipitation in areas where the groundwater table is close to the surface may result in a reduced water unsaturated zone (Gunnarson 1999), which often results in growth reduction. A synchronized growth reduction in several bog pines can therefore be ascribed to periods of elevated groundwater table. In some cases, however, extreme water table lowering may also cause reduced tree growth (Linderholm et al. 2002). A positive impact on peatland tree growth caused by increased July precipitation has been documented by Vitas and Erlickytë (2007), probably as a result of shallow spreading roots at wet sites. This means that it is possible to study groundwater fluctuations based on peatland trees, but that there is a potential problem in differentiating the causes of growth variations.

### *Reasons of tree establishment on peatlands*

There are at least two possible reasons why tree establishment occurs on peat bogs; (1) as a natural step in the peat succession when the surface of a raised bog rises above the groundwater table, (2) when the groundwater table is lowered as a result of climate change. It is very difficult to identify the cause of a single horizon of stumps. If, however, two or more stump horizons occur in the same bog, it is likely that at least one of them is caused by altered climatic conditions.

To determine the reason behind an establishment of trees on a bog, the wood material first has to be dated. Thereafter it may be possible to put the results into an environmental context and to understand why the bog surface conditions changed and became more favourable for tree growth. Regardless of the reason behind tree establishment on peatlands, tree growth variability will reflect climate-related changes during their lifetime. It is therefore of great importance that the development of bog-pine chronologies and the interpretation of their growth variability continues.

## Work in progress

New bog-pine chronologies from additional sites in southern Sweden are currently being developed. The aim of this work is to cover as much as possible of the Holocene, and to obtain time series from different sites covering the same time periods, which is of importance as growth variations can be attributed to other factors than climate change. *In situ* material enables more precise environmental reconstructions, which makes it urgent to focus future studies on sites with large amounts of unmoved sub-fossil wood.

Regarding other peatland tree species, tests on bog-alders have shown that it is extremely difficult to obtain climate reconstructions from this species. Correlations between different measured radii within the same samples were extremely weak, which made it difficult to create mean curves. Bogs with abundant oaks can be of interest, but such deposits appear to be quite rare in southern Sweden in comparison with Ireland, Scotland and Germany. Future studies will therefore focus on Scots pine as this species most often produces annual rings, is sensitive to environmental change and is common as sub-fossil material in south Swedish peat bogs. To improve the palaeoclimatic interpretation of south Swedish bog-pine chronologies and to strengthen derived environmental reconstructions, stable isotope analyses, root formation studies and peat stratigraphic approaches will be applied.

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# SECTION 3

# ARCHAEOLOGY

# Dendrochronology of oak (*Quercus* spp.) in Slovenia – an interim report

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## Introduction

The aim of our contribution is to survey the present state and future challenges of oak dendrochronology in Slovenia, a region that was until recently considered sub-optimal for the assembly of an oak reference tree-ring chronology and for using it for various purposes such as climate reconstruction and dating historical buildings or archaeological wood.

Oak - mainly represented by pedunculate (*Quercus petraea*) and sessile oak (*Q. robur*) - is the most important wood in European cultural heritage and dendrochronology. Currently, several multi-millennial chronologies of different tree species are in existence but the Central European oak chronology, reaching back to 8480 B.C. (Friedrich *et al.* 2004) is, for the time being, the longest tree-ring chronology in the world (for recent reviews see Čufar 2007, Haneca et al. 2009).

Recently, we assembled a 548-year long regional oak chronology for SE Slovenia which covers the period A.D. 1456-2003 (Čufar et al. 2008c). It is based on wood from living trees and historic constructions and proved to correlate significantly with local and regional oak chronologies up to 700 km apart in Austria, Hungary, Serbia, Czech Republic and South Germany. It also showed a good heteroconnection (agreement with chronologies of other tree species) with beech (*Fagus sylvatica*), ash (*Fraxinus excelsior*), and silver fir (*Abies alba*) in SE Slovenia.

A dendroclimatic analysis showed that tree-ring width variations in Slovenian oaks are highly significantly correlated with June precipitation (positive) and temperature (negative) (Čufar et al. 2008b, c). That is why this chronology was used to reconstruct June climate conditions over the last five centuries by applying the De Martonne aridity index (Čufar et al. 2008b). The reconstructed past climate anomalies in terms of negative and positive deviations from the long-term mean helped us to identify 50 years with a likely dry and hot June, as well as 40 years with a likely wet and cool June. Historic sources and chronicles used to validate the reconstruction in the pre-instrumental period (before 1896) confirmed that ten years with a strong negative deviation of the aridity index coincide with years of drought, extremely hot summers or crop failures. In contrast, five years with strong positive deviations of the aridity index correspond to years with cool and rainy summers (Čufar et al. 2008b).

Significant teleconnections of the Slovenian oak chronology with chronologies of remote sites indicate that oak growth in Europe is driven and controlled by a common factor - climate. On the other hand, the positive and negative deviations from the average tree-ring width, identified in the Slovenian oak tree-ring chronology, do not exactly coincide with corresponding deviations in central and western Europe, expressed for instance by the pan-European signature years of oak (Kelly et al. 2002).

Since we consider tree-ring chronologies as ‘living organisms’, we continue to improve and prolong the Slovenian oak chronology with the aim to use it for various purposes. In this contribution we present recently investigated and dendrochronologically dated wooden objects of the Slovenian cultural heritage. We discuss the importance of these objects to improve the Slovenian regional oak chronology and on the likelihood to prolong it and to use it for the development of dendrochronological research in neighbouring countries.

## Material and Methods

We investigated 16 wooden rural buildings, mainly hay racks and houses in the Dolenjska region, around Novo mesto in SE Slovenia (approx. 45°48'N, 15°11' E) in co-operation with the Institute for the Protection of Cultural Heritage, Basic Unit Novo mesto.

We collected data on these objects, evaluated the stand of their preservation and characteristics of wooden constructions, identified the wood species, and performed dendrochronological analyses. The samples for dendrochronology were collected by coring or sawing. The number of samples per building varied in accordance with the availability and characteristics of the timbers.

The wood samples were then polished and the tree-ring widths measured to the nearest 0.01 mm. The tree-ring series were visually and statistically cross-dated and compared with each other. We then established non-detrended, raw-data chronologies for each building and cross-dated them with the oak chronology of SE Slovenia (Čufar et al. 2008c) using standard dendrochronological procedures.

## Results and Discussion

Oak (*Quercus petraea* and *Q. robur*) was the dominant wood in all buildings. For each of the buildings we constructed a tree-ring chronology based on 2 to 9 tree-ring series. The time spans of these object-chronologies, their 'sample depth', and the parameter of cross-dating (t-value after Baillie and Pilcher 1973) with the SE Slovenian oak chronology are presented in figure 1a.

The length of the chronologies of buildings was 54 to 219 years; altogether they span the period from 1655 to 1966. The oldest building is dated to 1788 and the youngest to 1966. The end dates of the object-chronologies in most cases represent a *terminus post quem* since at least few outermost tree rings were usually missing.

The dating shows that some wooden constructions are still original whereas others have been thoroughly renovated. The determined age of the buildings helped to evaluate their importance and to include them into the list of monuments of cultural heritage of the Republic of Slovenia.

The tree-ring chronologies of all buildings investigated fall within the time span covered by the Slovenian regional chronology (1456-2003) and do not contribute to extend it further back into the past. Nevertheless, they can help to improve its replication. Our work in the last years showed that wood having grown before 1500 is extremely rare in rural buildings. Therefore, other sources of old wood should be found to prolong the chronology. Such older timbers seem to be preserved in castles. The constructional timber in the castle Pišece (located near the border with Croatia), for instance, already helped to extend the Slovenian regional oak chronology, even if only for some years, to A.D. 1442 (Čufar et al. 2008c).

Since the building timbers originated from local forests, the chronologies assembled are local in nature. Such local chronologies are important for dendro-provenancing studies – a new sub-field of tree-ring research (Eckstein & Wrobel 2007). The dating of a ship wreck found near Venice (Fig. 1b, white circle SW from Ljubljana) confirmed the possibility of dating and dendroprovenancing (Martinelli & Čufar, unpubl.)

The map (Fig. 1b) shows the location of the buildings in the area which corresponds with the area of the Slovenian oak chronology (black squares) and locations of chronologies in Austria, Hungary, Italy (white circles), and Serbia (black spot near Beograd) that could be successfully cross-dated with the Slovenian oak chronology (Čufar et al. 2008c, Grabner, Grynaeus, Morgos personal communication).

Until recently there was nearly no information on tree-ring characteristics of oaks from Croatia but co-operation with Croatian archaeologists, where during an initial study no wood appropriate for dendrochronological dating was found (Čufar et al. 2006), lead to first encouraging results. There were successfully dated timbers in the Varaždin Old Castle (Čufar & Šimek 2008) and in Torečec gradić (Čufar et al. 2008a) (Fig. 1b, black spots NE of Zagreb). The dating of these timbers in Croatia to 1415 and 1263 (*terminus post quem*) was only possible in co-operation with the dendrochronological laboratory of the University of Natural Resources and Applied Life Sciences, Vienna, Austria where an over 800-year long oak chronology has been assembled (Wimmer & Grabner 1998). Since this Austrian chronology and the Slovenian regional one cross-date well ($t_{BP}$=9.7), in future both of them could act as powerful reference chronologies for establishing a chronology network in the area south and southeast of the Alps.

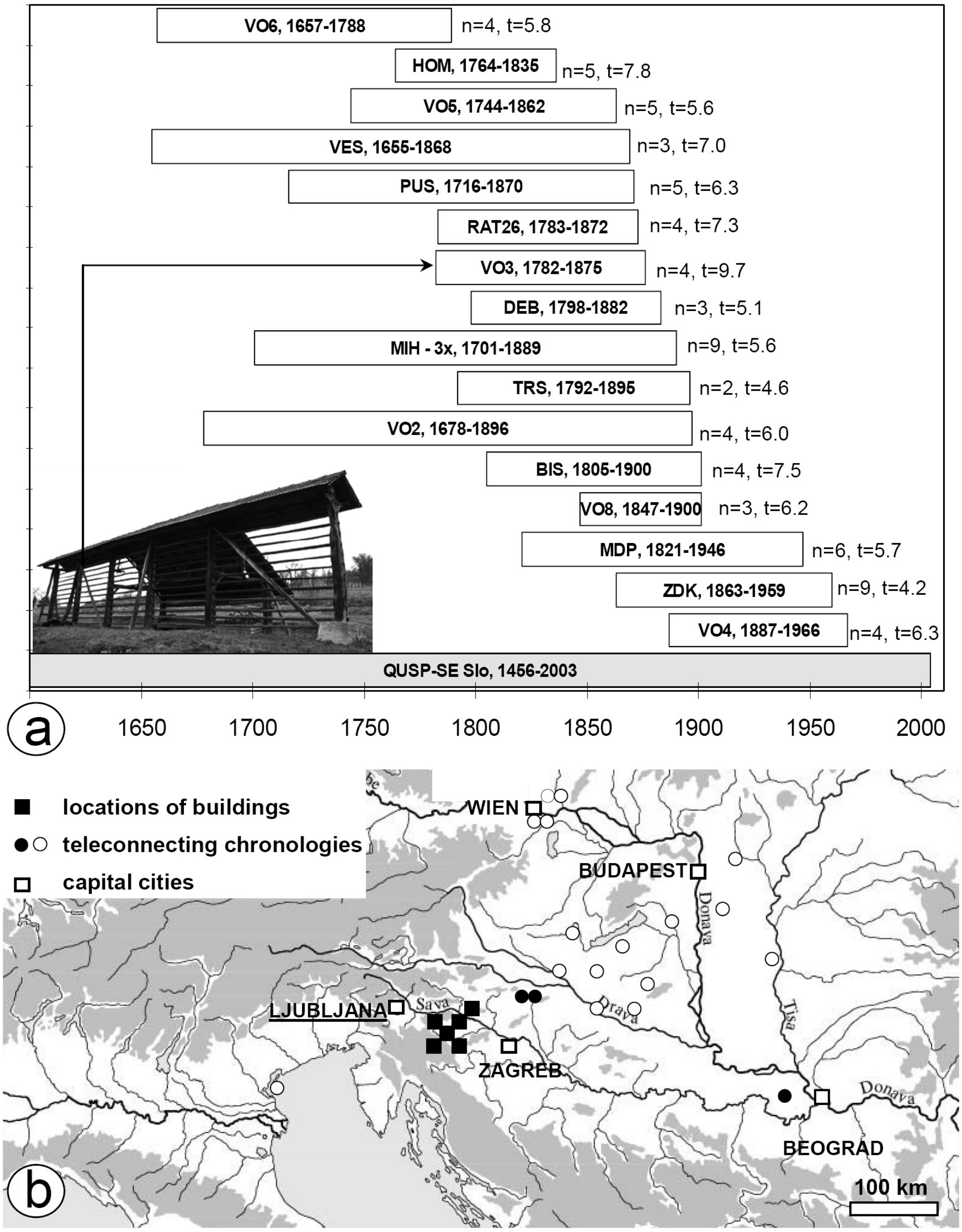

*Figure 1: (a) Time spans of the object-chronologies of 16 wooden buildings in SE Slovenia dated with the Slovenian oak chronology. For each of the buildings the following information is given: code of the building, time span of the chronology, number n of samples included in the chronology, and t-value after Baillie and Pilcher for comparison with the Slovenian oak reference chronology (QUSP-SE Slo). The inset shows a typical hay rack dated 1875. (b) Map of the sampling area with locations of buildings (black squares) and chronologies constructed by the laboratories in Austria, Hungary, Italy (white circles) and Slovenia (black circles) that were teleconnected significantly to the Slovenian regional chronology. Map ZRC SAZU.*

In search to prolong the Slovenian oak chronology we found considerable amounts of wood in the Ancient Roman period (Horvat, Tolar & Čufar, unpublished data) and in prehistoric pile dwellings that mainly existed from 3500 to 2500 B.C. (Velušček & Čufar 2002); these hitherto 'floating' tree-ring chronologies are for now dated by radiocarbon only.

In future, co-operation between laboratories in a wider region would be necessary to fill the spatial and chronological gaps and to establish a network of regional oak chronologies.

## Acknowledgements

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# Dating and properties of subfossil oak wood

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## Introduction

### *Dendrochronology of subfossil wood*

Subfossil wood is unfossilized wood which has been deposited in rivers, swamps or moraine sediments for hundreds or thousands of years (Kaennel & Schweingruber 1995). In former literature, subfossil oak trunks are referred to as "black oak" because of their colour (Kalicki & Krąpiec 1995). The change of the wood shade into black is caused by ferric components dissolved in water reacting with tannins present in oak. The intensity of the shade is primarily determined by the time for which the wood has been deposited and the nature of sediments. Besides the changes of the shade, there are also changes in physical and mechanical properties (Govorčin & Sinković 1995). Oak forests started appearing on the banks of central European rivers about 10,000 years ago, it means at the beginning of the Holocene (Becker 1982, Leuschner et al. 1986). However, the process in which the trunks were deposited is disputable. Most often it is considered that banks were eroded in meanders or during large floods (Kalicki & Krąpiec 1995). The fallen trees then soaked up water and settled in deposited layers of channel alluvium under the water surface (Krąpiec 1996). The trunks were gradually hidden beneath the accretion on the slip-off slope during the channel migration (Kalicki & Krąpiec 1995). The slip-off slope is the relatively gentle slope at the inner edge of a meander. That is why subfossil oak trunks are often found in gravel pits when deposited sand and gravel is mined (Krąpiec 1996). The lifespan of riverside oaks which grew on river banks during the Holocene is relatively short – 95% of the trees only have 150–400 growth rings. This fact is associated to the frequency of the above mentioned floods (Becker 1993). The age of wood is usually found out by the dendrochronological analysis. In the Czech Republic, this is a common method used for dating of wooden finds. To be able to date them there has to be a standard chronology available. The standard chronology is created for each tree species individually by gradual overlapping of growth ring sequences towards the past (Rybníček 2007). If the standard chronology for the particular species and the particular areas is not sufficiently long, dating is not possible and another way to establish the age has to be found. In such cases, the radiocarbon method is used; the method establishes the age of the organic material on the basis of the proportion of stable and unstable carbon (Libby 1955).

### *Subfossil wood properties*

During the time subfossil wood is deposited in the specific conditions a number of complicated physical and chemical processes occur. These finally result in its fossilization (Habětín & Knobloch 1981). When the processes are in progress the wood structure changes which is naturally also reflected in the wood properties. Wood properties are affected by many factors, the most important of them being probably its chemical composition (Požgaj 1997). As regards the chemical composition, subfossil wood differs from recent wood by a considerably lower proportion of hemicelluloses. This is caused by the fact they are easily eluted in humid environment (Bednar & Fengel 1974, Govorčin & Sinković 1995, Wagenführ 2000). Therefore, when wood is deposited in the soil and water affects it, some substances are removed and carbonate of lime and silica sediment on the wood surface (Govorčin & Sinković 1995). For examinations we have chosen:

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density, dimensional changes – swelling and shrinking, modulus of elasticity and compressive strength parallel to the grain, and hardness.

### *Physical properties*

Density affects all the other physical and mechanical properties of wood to a considerable extent (Požgaj 1997, Gryc & Horáček 2007). When the measured density of subfossil oak wood is compared with recent wood, the values are more or less the same, or slightly rising (Govorčin & Sinković 1995). With regard to dimensional changes, there are considerable differences found when the values of recent and subfossil wood are compared. Wagenführ (2000) and Govorčin & Sinković (1995) present approximately twofold values of the percentage of subfossil oak shrinkage vis-à-vis recent oak.

### *Mechanical properties*

Generally, mechanical properties of subfossil oak wood are smaller than the properties of recent oak (Govorčin & Sinković 1995). One of the most significant mechanical properties is compressive strength parallel to the grain. Compressive strength parallel to the grain is the basic ways of applying stress. The cross-section of wood is subjected to perpendicular pressure, i.e. the pressure is applied in the direction of the main building components of wood. Deformation takes a form of the material shortening (Matovič 1993). Compressive strength parallel to the grain of subfossil oak corresponds to about 70–80 % of the strength of recent oak (Bednar & Fengel 1974).

Because, as far as subfossil wood is concerned, the process of silicification, which means the replacement of wood cell structure by minerals, is involved, it is interesting to focus on wood hardness (Carrión 2003). The hardness is the ability of wood to resist identation of another object into its structure. There are two tests used for establishing the hardness of wood: Brinell hardness test and Janka hardness test (Požgaj 1997). The professional literature states that the values of subfossil oak hardness are lower even though the cell structure was replaced by harder minerals.

## Materials and methods

### *Sampling*

Proper sampling for dendrochronological measuring is the main prerequisite for sample dating (Rybníček 2007). As the subfossil trunks were found at differing locations and differing positions, taking of individual samples demanded specific approaches. Sampling was carried out using a chain saw. This technique provided us with discs needed for dendrochronological analysis and larger pieces for the establishment of physical and mechanical properties.

Samples were taken in five locations; three of them were a river banks, two were gravel pits. The first location was the bed of the Bečva River, near Osek nad Bečvou. The village is located in the Přerov district, about 10 km to the east of Přerov. The second location was in the Morava River basin near Strážnice in South Moravia, which is close to Slovakian border. The last place where the samples were taken from a river basin was the Lužnice River near Majdalena in south Bohemia, at Austrian border. Further, samples were taken from gravel pit Tovačov, about 12 km to the west of Přerov. The last location is the gravel pit between the villages of Kostomlátky and Doubrava, located 5 km to the west of Nymburk. The pit lies on the Labe River.

### *Dendrochronology*

At least two perpendicular directions were selected on the discs. The disc surface was worked in the two directions so that the ring borders were apparent. Samples prepared in such a way were measured using a specialized measuring table equipped with an adjustable screw device and an impulsemeter recording the interval of table top shifting, i.e. the tree ring width (Rybníček 2007). The tree ring width is measured in the direction perpendicular to the ring border with 0.01 mm accuracy. The obtained tree-ring series were compared using the PAST 4 application. The synchronizable curves were used to create an average ring series which was then compared with available oak standard chronologies from Germany, Austria and Poland. The samples which could not be dated in this way were subjected to radiocarbon dating, the C14 method.

### *Wood density*

The wood density is weight per unit volume with specific moisture (Požgaj 1997). The density was found out in compliance with ČSN 49 0108. For the actual measuring, we used testing samples of 20 × 20 mm in transversal dimensions and 25 ± 5 mm in length. Their weight was taken with accuracy of 0.01 g and dimensions with accuracy of 0.1 mm (Matovič 1993).

### *Dimensional changes*

Wood shrinking is a process when wood dimensions are reduces as a consequence of a loss of bound water (Požgaj 1997). Shrinkage of subfossil wood was found out in compliance with ČSN 49 0128. For the actual testing, we used testing samples of 20 × 20 mm in transversal dimensions and 30 mm in length. The previously measured samples were dried in the temperature of 103 ± 2°C until the moisture content was 0% [completely dry] and then weighed again. Sample can be referred to as completely dry when there is no weight difference greater than 0.02 mm between two processes of weighing within the interval of 2 hours (ČSN 49 0128).

Swelling is the ability of wood to expand its dimensions by accepting bound water (Požgaj 1997). Swelling of subfossil wood was found out in compliance with ČSN 49 0126. The same samples were used for the testing of swelling as for the testing of shrinking. The completely dry samples obtained in the process of shrinkage measuring were used for the measuring of swelling. The samples that had cracked during drying were not included. The samples previously measured were drenched in distilled water with the temperature of 20 ± 2 °C until their dimensions were stable. Then they were measured again.

### *Mechanical properties*

Mechanical properties were examined for normalized moisture of 12 %.

### *Compression strength parallel to the grain*

The compression strength parallel to the grain was examined in compliance with ČSN 49 0110. Using ZWICK Z050 universal testing device pressure was applied to climatized/conditioned samples with the dimensions of 20 × 20 × 30 mm evenly with constant speed. Compression strength parallel to the grain was expressed in MPa (ČSN 49 0110). Results were rounded off to the nearest 0.5 MPa.

### *Static hardness*

The static hardness of wood was examined using Janka method in compliance with ČSN 49 0136. We used climatized/conditioned samples with the dimensions of 50 × 50 × 50 mm and ZWICK Z050 universal testing device. A steel ball (an indenter) with the radius of 5.64 mm was forced into the depth of 5.64 mm, which created an indented area of 1 cm$^2$. The force necessary for indenting of the ball directly provides the hardness per 1 cm2, which was converted to MPa. As we assumed the material will be more fragile, we only forced the ball into the half depth – 2.82 mm (Matovič 1993).

## Results

### *Dendrochronolgy*

All samples were dendrochronologically processed. Some of them were well synchronizable, therefore 4 average tree-ring curves were created (Tab. 1). The average tree-ring curve from Strážnice was dated using Moravian oak standard chronology. The reliability of the dating has been confirmed by statistical indicators (Tab. 2) as well as optical comparison of curves (Fig. 1). The average tree-ring curve of samples from Majdalena was reliably dated using Czech oak standard chronology (Tab. 3, Fig. 2). The remaining two average tree-ring curves (Tovačov 01 and Tovačov 02) and the tree-ring curve from Kostomlátky were sent out to be dated by the radiocarbon method.

*Table 1: Dating of average tree-ring curves*

| *average annual ring curves* | *number of annual rings* | *dendrochronological dating* | *standard chronology* | *radiocarbon dating* |
|---|---|---|---|---|
| *Tovačov 01* | *182* | *–* | *–* | *2675–2275 BC* |
| *Tovačov 02* | *204* | *–* | *–* | *265–50 BC* |
| *Kostomlátky* | *132* | *–* | *–* | *165 BC–241 AD* |
| *Strážnice 01* | *112* | *1322* | *morges* | *–* |
| *Majdalena 01* | *80* | *1519* | *czges* | *–* |

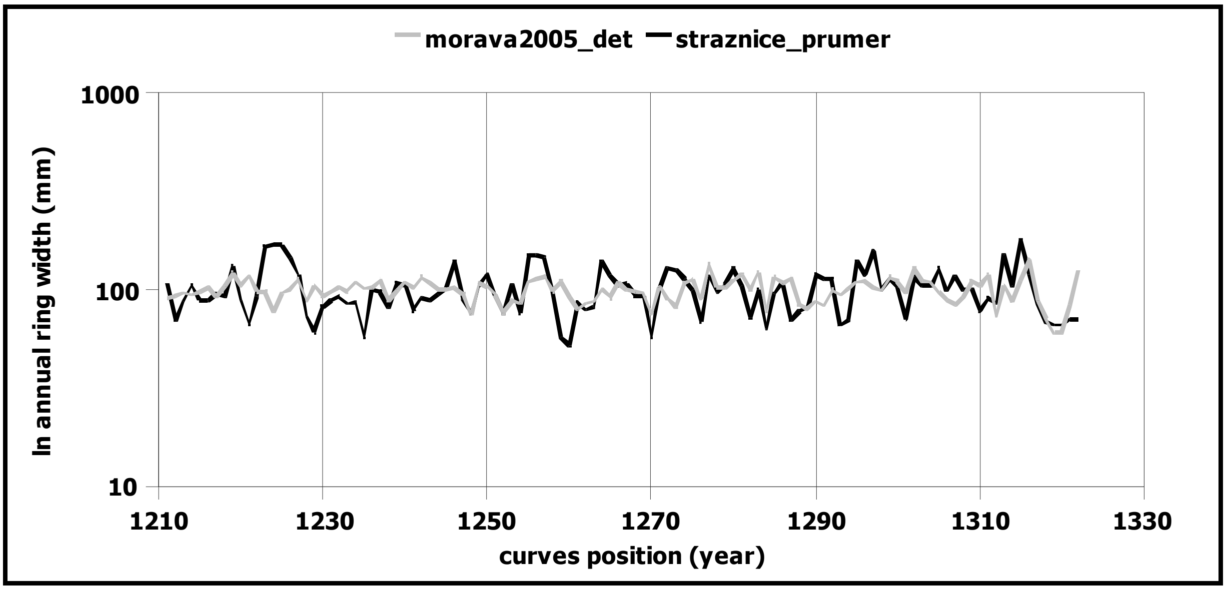

*Figure 1: Synchronization of the average tree-ring curve from Strážnice (black) with the Moravian oak standard chronology morges 2005 (grey)*

*Table 2: Results of correlation of the average tree-ring curve from Strážnice with the Moravian oak standard chronology morges 2005*

| *standard chronology* | *TBP* | *THO* | *GI* | *Overlap* | *EndYear* |
|---|---|---|---|---|---|
| *czges2005_det* | *6.72* | *7.53* | *73.8* | *80* | *1519* |

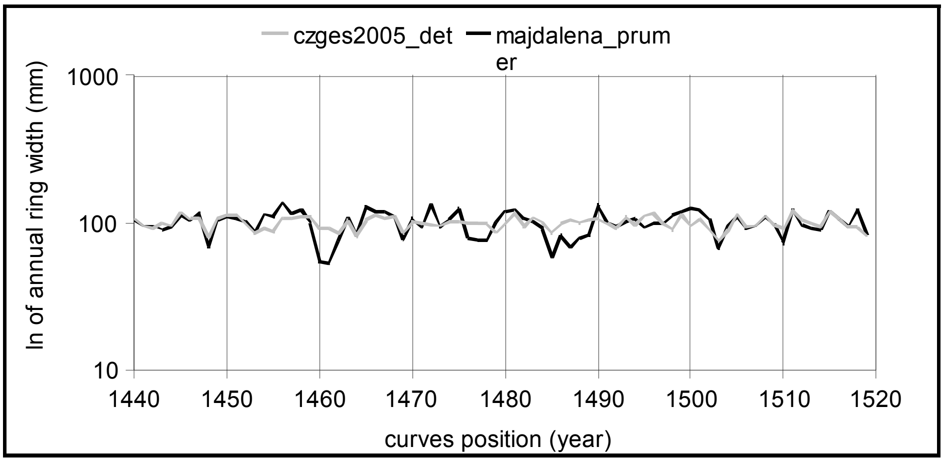

*Figure 2: Synchronization of the average tree-ring curve from Majdalena (black) with Czech oak standard chronology czges 2005 (šedě)*

*Table 3: Results of correlation of the average tree-ring curve from Majdalena with Czech oak standard chronology czges 2005*

| *standard chronology* | *TBP* | *THO* | *GI* | *Overlap* | *EndYear* |
|---|---|---|---|---|---|
| *czges2005_det* | *4.92* | *5.28* | *62.9* | *112* | *1322* |

### *Physical properties*

### *Wood density*

Table 4 shows the results of subfossil wood density from individual locations. The samples from Osek nad Bečvou correspond to the density of recent wood. However, there is a considerable difference in the samples from Tovačov, where the density is about 100 kg.m$^{-3}$ lower and it decreases with age. On the contrary, the density of the sample from Kostomlátky achieves quite high values.

### *Dimensional changes*

Table 4 shows the values obtained in measuring the shrinkage of subfossil oak. It is obvious that the percentages of shrinking are quite high and the differences between location are not very significant. Generally, we can conclude that the values correspond to the values presented in professional literature. Compared with recent wood, the values of subfossil wood are approximately twofold. As far as the swelling of subfossil wood is concerned, we can see the conclusion is the same as in case of shrinking. The values of swelling are similar to the values of shrinking.

*Table 4: Values of physical properties of subfossil oak*

| *properties* | *location / source* | *Tovačov (no.6)* | *Tovačov (no.19)* | *Osek nad Bečvou* | *Kostomlátky* | *Govorčin, Sinković (1995)* | *Vavrčík et al. (2008)* | *Tsoumis (1991)* |
|---|---|---|---|---|---|---|---|---|
| | *age of wood* | *2490–2190 BC* | *265–50 BC* | *945–405 BC* | *165 BC–241 AD* | *cca 2050 BC* | *recent* | *recent* |
| *wood density (kg.m$^{-3}$)* | *moisture 0 %* | *529.0* | *575.0* | *669.0* | *746.0* | *735.0* | *618.2* | *690.0* |
| *shrinkage (%)* | *longitudinal* | *0.88* | *0.42* | *0.46* | *0.91* | *1.09* | *–* | *0.40* |
| | *radial* | *7.43* | *6.53* | *8.36* | *10.36* | *9.37* | *4.70* | *4.00* |
| | *tangencial* | *15.89* | *11.78* | *15.32* | *14.41* | *17.22* | *8.40* | *7.80* |
| | *volumetric* | *22.83* | *17.85* | *22.74* | *23.97* | *25.79* | *13.00* | *12.20* |
| *swelling (%)* | *longitudinal* | *0.67* | *0.45* | *0.86* | *1.28* | *–* | *–* | *–* |
| | *radial* | *5.95* | *6.63* | *8.46* | *11.93* | *–* | *–* | *–* |
| | *tangencial* | *11.23* | *13.70* | *14.93* | *17.08* | *–* | *–* | *–* |
| | *volumetric* | *18.64* | *21.79* | *25.72* | *32.71* | *–* | *–* | *–* |

## *Mechanical properties*

### *Compression strength parallel to the grain*

Table 5 presents average values of the compression strength parallel to the grain of subfossil oak wood from the examined locations. The strength does not exceed the limit of 40 MPa and the modulus of elasticity does not exceed the limit of 9500 MPa.

### *Static hardness*

The resulting average values of the static hardness of subfossil oak in all directions are presented in table 5. The hardness in the longitudinal direction exceeds 40 MPa, whereas the hardness in the transversal directions is about half of the value. Furthermore, it is slightly higher in the radial direction than in the tangential direction. The range of values of hardness in the transversal directions is quite wide in dependence on the density and the age of the wood – between approximately 19 MPa and 34 MPa.

*Table 5: Values of compression strength parallel to the grain and static hardness of subfossil oak*

| *properties (moisture 12 %)* | *location / source* | *Tovačov (vz.19)* | *Osek nad Bečvou* | *Tovačov (vz.6)* | *Kostomlátky* | *Wagenführ (2000)* | *Ugolev (1975)* |
|---|---|---|---|---|---|---|---|
| | *age of wood* | *265–50 BC* | *945–405 BC* | *2490–2190 BC* | *165 BC–241 AD* | *subfossil* | *recent* |
| *wood density (kg.m$^{-3}$)* | *moisture 0 %* | *575.0* | *669.0* | *529.0* | *746.0* | *630.0* | *650.0* |
| *compression parallel to the grain (Mpa)* | | *32.63* | *39.95* | *29.40* | *39.19* | *38.00* | *57.50* |
| *Modulus of elasticity (MPa)* | | *4634* | *9384* | *4846* | *7640* | *–* | *14600* |
| *hardness (Mpa)* | *longitudinal* | *42.8* | *–* | *41.6* | *52.4* | *44.0* | *67.5* |
| | *radial* | *27.3* | *–* | *22.3* | *33.5* | *23.0* | *56.0* |
| | *tangencial* | *20.6* | *–* | *19.1* | *27.2* | *–* | *49.0* |

## Conclusion

The aim of the study was dendrochronological or radiocarbon dating and the examination of selected physical and mechanical properties of subfossil oak wood, and the comparison of the obtained results with the data presented in literature on subfossil and recent oak.

All samples were dendrochronologically processed and 4 average tree-ring curves were created. It was possible to date the curve from Strážnice (1322 AD) (Fig. 1, Tab. 2) and from Majdalena (1519 AD) (Fig. 2, Tab. 3) using oak standard chronologies for the Czech Republic. The radiocarbon method dated the average tree-ring curves of Tovačov 01 back to 2675–2275 BC, and Tovačov 02 to 265–50 BC and Kostomlátky to 165 BC–241 AD (Tab. 1).

Besides the basic indicator of density, the selected physical properties include the dimensional changes of wood, i.e. shrinking and swelling. Regarding mechanical properties, the attention focused on the compression strength parallel to the grain and the hardness of wood examined in all the three anatomical directions.

The results of wood density presented in table 4 show that there are considerable differences between individual locations. While the density of the sample from Osek nad Bečvou approximates the values of recent wood, the density of the sample from Kostomlátky, the youngest of the explored samples, significantly exceeds 700 kg.m$^{-3}$. In contrast, in the samples from gravel pit Tovačov the density is about 100 up to 200 kg.m$^{-3}$ lower than presented in professional literature.

The average values of shrinking and swelling of samples from Osek nad Bečvou, Tovačov and Kostlomlátky (Tab. 4) do not differ much, even with respect to their significantly differing age. Therefore, we can conclude that shrinking and swelling of subfossil oak does not change with time. When compared with the data presented in literature (Tab. 4), our results show that the dimensional changes are twice as high as those of recent oak wood. In contrast to the values of shrinking, the results of wood swelling in some cases vary to a great extent, especially in samples from Tovačov and in volumetric dimensional changes of samples from Kostomlátky. Because the values of subfossil wood swelling are not available in literature, they could not be compared.

The compression strength parallel to the grain is presented in literature to range between 70 and 80 % of the strength of recent oak. The resulting values of strength of the samples from Osek nad Bečvou 39.58 MPa and Kostomlátky 39.19 MPa (Tab. 5) confirm the theory. The values are comparable with results of subfossil oak presented by e.g. Wagenführ 2000 (Tab. 5). On the other hand, the strength of the Tovačov samples is considerably lower (30.33 MPa and 29.30 MPa), reaching about 55 % of the strength of recent oak. The lower strength of these samples is to a considerable extent affected by their lower density.

Wood hardness was tested using Janka method. Two samples of a different age from Tovačov and a sample from Kostomlátky were used to test the hardness. The averages of the resulting values of Tovačov samples are around 42 MPa in the longitudinal direction, 22–27 MPa in the radial direction and around 20 MPa in the tangential direction (Tab. 5). On the other hand, the Kostomlátky sample achieves much higher values even with respect to its higher density. The hardness of wood is 52.4 MPa in the longitudinal direction, 33.5 MPa in the radial direction and 27.2 MPa in the tangential direction. The lower hardness in the tangential direction in comparison with the radial direction can be explained by the orientation of pith rays in the wood. The results show that the hardness is lower in comparison with recent wood (Tab. 5), but also that there is a greater difference between the hardness in the longitudinal and the transversal directions. The hardness in transversal directions of subfossil wood amounts to about 45–65 % of the hardness in the longitudinal direction, whereas the hardness in transversal directions of recent wood amounts to about 70–80 % of the hardness in the longitudinal direction.

The outcome of the research is that the properties of subfossil oak wood in comparison with recent wood are quite different. The density is highly variable, the dimensional changes are considerably higher and mechanical properties are approximately 20–30 % lower. There are more possible explanations for the changes of properties. One of the theories is a biological degradation of wood which causes the decomposition of wood structure, and thus the change of properties (Klaassen

2008). Another theory can be based on the difference of the compositions of subfossil and recent oak wood.

It is hard to assess the influence of age on the properties of the samples as the samples from Tovačov are considerably different from all the others in all their parameters. However, if we consider the samples from Tovačov separately from the samples from Kostomlátky and Osek nad Bečvou, it is possible to use the data in table 4 and state that with the increasing age the wood density decreases. The same dependence is valid for the other examined properties because all of them are considerably affected by the density. However, to confirm or reject this theory it will be necessary to analyse many other samples from various locations.

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# SECTION 4

# WOOD ANATOMY & SEASONAL DYNAMICS

# Seasonal growth dynamics of different tree species and their climatic control in Munessa Forest, Ethiopia

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## Introduction

Knowing seasonal tree growth dynamics in tropical regions is the prerequisite for understanding annual wood formation, which is a basic parameter for many applications in forest ecology and management and dendrochronological studies. In Ethiopia, some tree species exhibit a variable wood anatomy due to regional differences in seasonal rainfall patterns (Wils et al. 2009). Hence, trees of the same species (e.g. *Juniperus procera*, Cupressaceae) may show clearly distinct ring boundaries or faint to indistinct ring boundaries including many wood anatomical anomalies like wedging rings and multiple rings, causing serious constraints for cross-dating (Wils and Eshetu 2007, Wils et al. 2009, Sass-Klaassen et al. 2008). Nevertheless, under suitable climatic conditions it may be possible to cross-date samples within a site and to construct chronologies that are correlated among each other and with climate variables (Couralet et al. 2005, 2007, Sass-Klaassen et al. 2008). *Acacia* species from the Ethiopian savanna lowlands have been successfully used for dendroclimatological studies (Eshete & Ståhl 1999, Gebrekirstos 2006, Gebrekirstos et al. 2008). However, the seasonal growth characteristics of Ethiopian tree species are so far unknown (Sass-Klaassen et al. 2008). Thus, our aim is to record cambial growth dynamics and seasonal variations of wood formation in relation to climate forcing to provide a basis for the interpretation of wood anatomical structures and tree-ring formation in the Ethiopian highland forests.

## Material and Methods

The study area is located in the tropical mountain forest of Munessa-Shashamene in the southeast of Ethiopia (7°26'N, 38°52'E; 2300 m a.s.l.), 240 km south of the capital Addis Ababa. The regional climate shows two rainy seasons: An unreliable short rainy season from March to May and the major rains from July to September. Mean annual rainfall at the study site amounts to 1121 mm and mean annual temperature is 15 °C. The forest is highly disturbed by the local population due to selective felling and cattle grazing. Indigenous tree species include evergreen conifers (*Podocarpus falcatus* and *Juniperus procera*), evergreen broadleaved trees (*Syzygium guineense* and *Prunus africana*) and deciduous trees (*Croton macrostachys* and *Celtis africana*). Vast areas of the forest were converted to plantations of *Cypressus lusitanica*, *Eucalyptus saligna* and *Pinus patula*. The latter species is also of interest for dendroecological studies.

We installed 28 electronic point dendrometers (Ecomatik, Germany) in heights between 1-1.5 m on the stems of several individuals of the species mentioned above. Measurements of stem radius changes were taken in 30 min. intervals to detect short-term stem diameter variations that result from fluctuations of the water status of the tree. In addition, long-term growth trends are recorded that help to characterize the season of active cambial growth (Biondi et al. 2005, Bräuning et al. 2008, 2009). Here, we only discuss seasonal stem diameter changes as indicated by the cumulative growth which was constructed from the daily maximum stem diameters.

Cambial activity was studied by microcores collected in monthly intervals with a trephor microcorer (Rossi et al. 2006). Microsections of 20 μm thickness were cut with a sledge microtome and stained with solutions of astra blue and safranin red to highlight living and lignified cells. Wood

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tissues that allowed the localisation of annual growth boundaries were used to align the consecutive microsection topographically. In some cases, when the microcores were too short to show the former growth boundary, they were discarded from further analyses. Local climate data are measured within a distance of half kilometre from the study sites. Water pressure deficit was calculated from the saturation vapour pressure of the air minus the actual saturation vapour pressure according to Häckel (1993).

## Results

Figures 1 and 2 present the combination of daily maximum dendrometer data and microsections of *Syzygium guineense* and *Celtis africana*. Both species begin cambial activity around May and formation of newly wood cells around June. The clarity of the growth boundaries varies between the consecutive microsections from clear to faint. Ring boundaries of the evergreen broadleaved tree *Syzygium guineense* are marked by a marginal parenchyma band that is often difficult to detect. A growth boundary of *Celtis africana* is characterised by a thin parenchyma band and larger vessel diameters in the earlywood. As indicated by the dendrometer curves, stem swelling occurs in April, before cambial cell formation, and characterizes a rehydration of the stem after the dry period.
The climatic influence on cambial activity is revealed by the cumulative dendrometer growth curves of five different species in combination with daily precipitation (grey bars) and water pressure deficit (black bars) shown in Figure 3. Totally independent of life form (coniferous, evergreen or deciduous broadleaved trees) all tree species react synchronously on increasing water availability after the dry period around beginning of April 2008, however with differences in the amplitude of stem diameter increase. The first rains of the short rainy season lead to a water uptake of the trees and a swelling of the stems that is not related to the formation on new cells. Intensive growth occurs during the rainy period from July to November, with different species showing different length of the growing period.

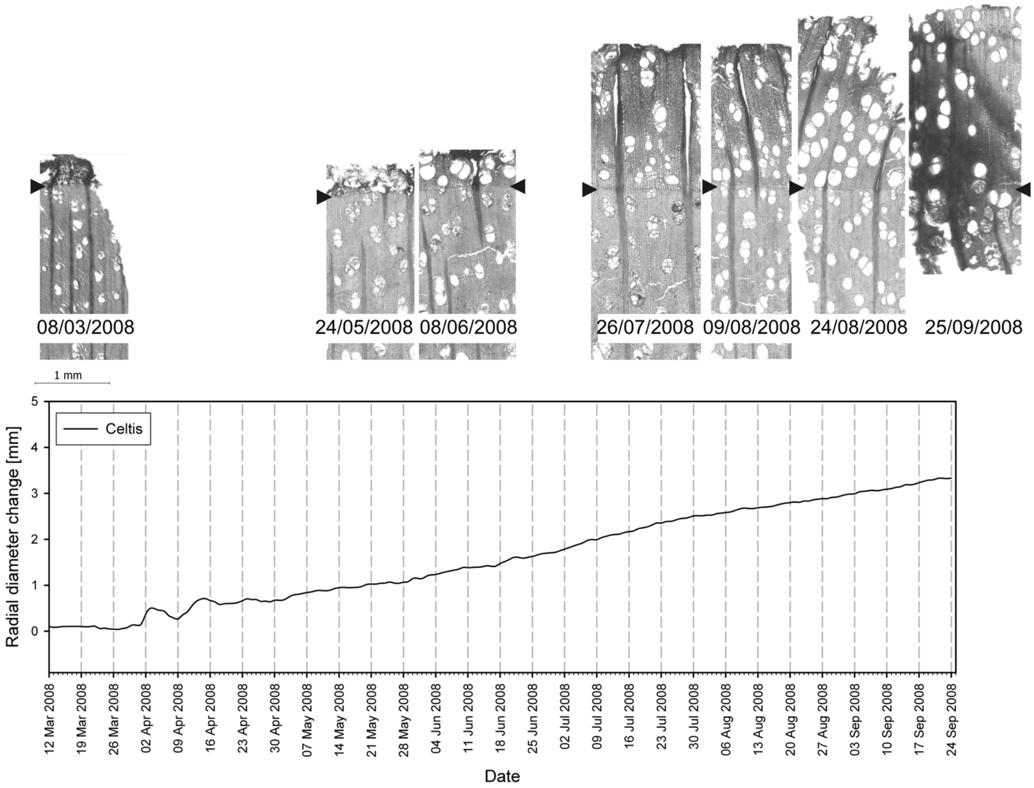

*Figure 1: Wood anatomical microsections and dendrometer curve for Celtis africana for the period March to September 2008. Dates below the microsections indicate the calendar date of sampling, black triangles mark identical wood tissues present in all cores that were used to align the microsections.*

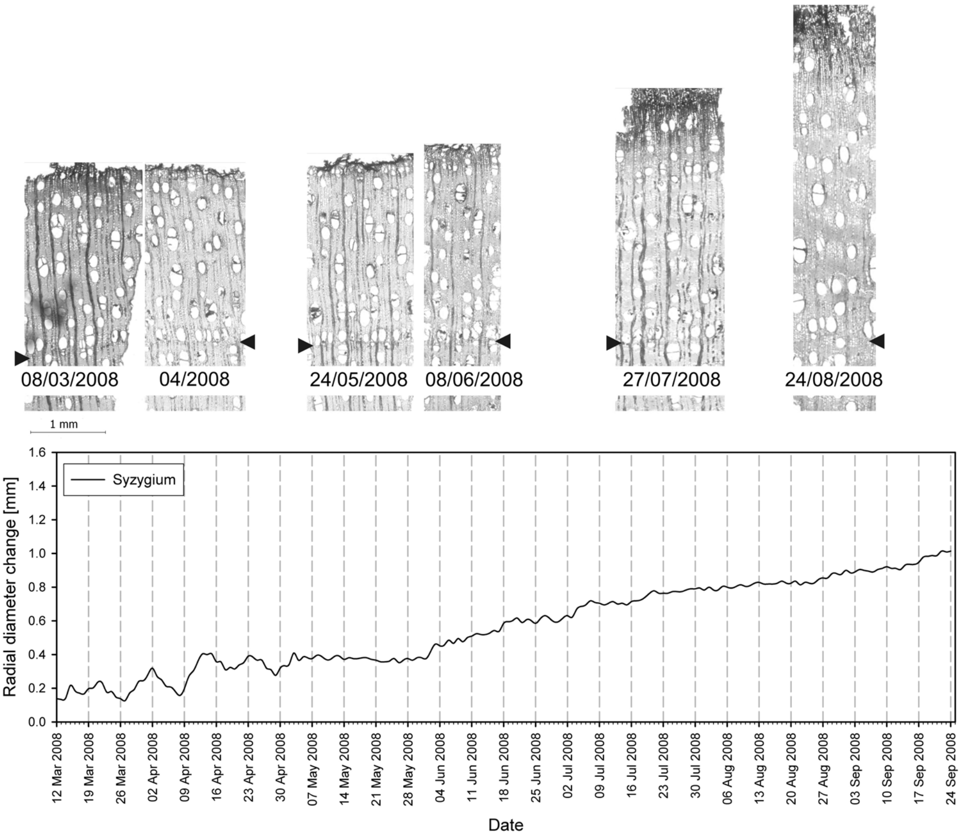

*Figure 2: Wood anatomical microsections and dendrometer curve for Syzygium guineense for the period March to September 2008. Dates below the microsections indicate the calendar date of sampling, black triangles mark identical wood tissues present in all cores that were used to align the microsections.*

*Syzygium guineense* shows low growing activity during the dry period between November 2008 and March 2009. In contrast, the deciduous broadleaved species *Celtis africana* and *Croton macrostachys* stop growing at the beginning of the dry season in November. The stem diameters of these trees stay more or less constant during the dry period and show first notable increase after the formation of the new generation of leaves around April 2009. The two evergreen broadleaved species *Prunus africana* and *Syzygium guineense* react differently. The stem diameter of *Syzygium* increased until February 2009. In contrast, the stem diameter of *Prunus* decreased until the first rains in April 2009. To distinguish passive stem swelling due to water uptake from active cambial growth, wood anatomical microcores will be analyzed in the near future.

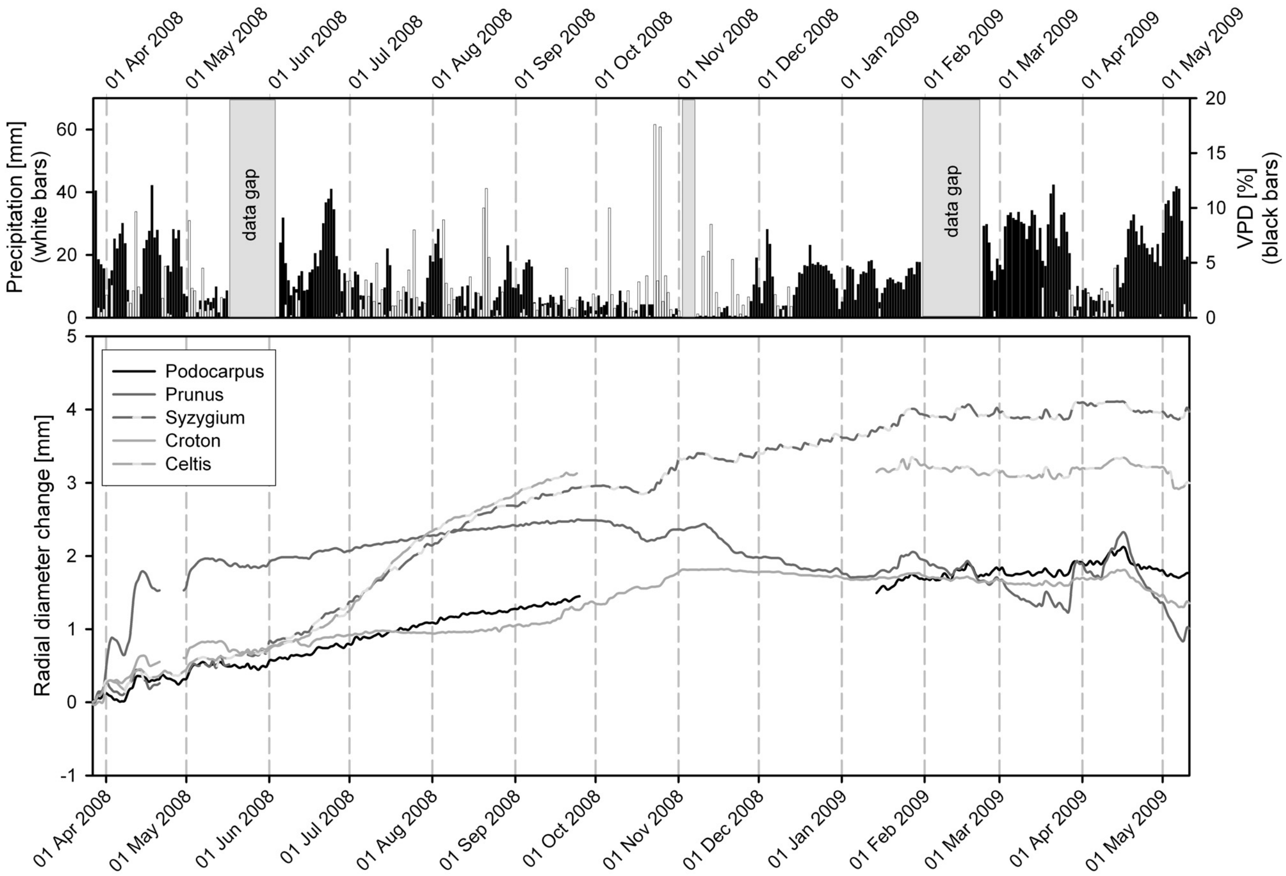

*Figure 3: Daily precipitation and vapour pressure deficit (upper panel) and cumulative dendrometer curves of five tree species (lower panel).*

## Discussion

The combination of dendrometer data and wood anatomy is a very useful approach to distinguish passive stem diameter increment due to water resaturation from active stem growth by new cell formation in tropical trees (Bräuning et al. 2008 a, b, Bräuning et al. 2009). The microsection studies demonstrate that the stem swelling phase that occurs at the beginning of the rainy season is not linked to cambial activity. Formation of new xylem cells does not occur before end of May or beginning of June in *Prunus africana* and *Syzygium guineense*. Hence, in addition to dendrometer measurements wood anatomical studies are of great importance to delimit the period of cambial activity and to link growth dynamics to seasonal climate variations in tropical regions.

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# Basic density of spruce wood, wood with bark, and bark of branches in locations in the Czech Republic

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## Introduction

The amount of wood of adequate quality for industry is continually decreasing. Therefore, it is necessary to use it more efficiently. Besides stem-wood also branch wood with bark, could be interesting for many purposes, like chemical and semi-chemical processing (ground wood, pulp, chips, production of agglomerated materials) and also for energy. One of the most important properties of wood is its density. For potential industrial utilization of branches we need to know their density as well (e.g. for purchase and sale of the material) is the basic density of wood, or of branch wood. In wood technology there exist several definitions of density. Basic density is expressed as the weight of dry material (wood, wood and bark, bark) at moisture content (MC) of 0% per maximum volume (moisture ≥ fibre saturation point) (Panshin & Zeeuw 1980). In Norway spruce (*Picea abies* (L). Karst.) the density of branch wood is generally higher than that of stem wood because the branches contain high proportion of compression wood. Compression wood is composed of compression tracheids which have round shapes, intercellular spaces, and thicker cell walls than tracheids of normal early or even late-wood (Nečesaný 1955, 1956, Timell 1986, Gryc & Vavrčík 2006). The aim of this paper is to study the variability of basic density of wood with bark, branch wood and branch bark of spruce (*Picea abies* (L). Karst.) from various forest sites in Czech Republic.

## Material and Methods

Ten different forest sites all over the Czech Republic were chosen to collect the material (Tab. 1). We randomly choose 6 trees at each location and from each of them took 1 branch from the central crown whorl. In addition we took one core at breast height (1.3 m above ground) from the each of the sampling trees. Such sampling design would allow us to obtain the results with 95% probability and 4–5% accuracy for the locations in question as previously shown by Chmelař (1992). The sampled branches were then cut into 1 cm discs at each 25 cm, starting at the branch basis. The discs were used define the basic density of the wood and the bark separately, and the wood with bark. The basic density ($\rho_k$) was calculated using the formula:

$$\rho_k = \frac{m_0}{V_{max}}$$

where $m_0$ is the weight of the material at MC= 0% (kg),
$V_{max}$ is the maximum volume of material (MC ≥ fibre saturation point) ($m^3$).

The wood volume was established using the Olesen's method (Olesen 1971). The samples were laid in beakers with water until their maximum dimensions were reached. Then they were dried with filter paper, bark was separated from the branch and using the Olesen's method, and the volumes of the wood and of the bark were determined separately. Afterwards, the samples were dried in oven at the temperature of 103±2 °C until their MC reached 0%. The weight was measured by using a laboratory balance, again for the wood and the bark separately. Finally the obtained results were processed with standard statistic methods.

*Table 1: Basic data on Norway spruce trees from ten locations in Czech Republic*

| Location | Forest type | Age | Average tree height (m) | Average diameter at breast height (cm) |
|---|---|---|---|---|
| 1 | 4B1 | 92 | 26 | 31.5 |
| 2 | 5M1 | 107 | 24 | 28.4 |
| 3 | 5K1 | 104 | 28 | 34.4 |
| 4 | 5B1 | 92 | 27 | 36.7 |
| 5 | 5F1 | 82 | 33 | 38.8 |
| 6 | 5O1 | 92 | 27 | 32.7 |
| 7 | 6M3 | 103 | 26 | 33.2 |
| 8 | 6K2 | 89 | 28 | 32.5 |
| 9 | 6F1 | 97 | 20 | 36.0 |
| 10 | 6O1 | 93 | 30 | 36.0 |

## Results

### Basic density of wood with bark

The average basic density of wood with bark is 514.69 kg·m$^{-3}$ (coefficient of variation 14.67 %), the values ranging between 496 and 542 kg·m$^{-3}$ in specific locations (Tab. 2). Table 3 shows the significance of arithmetic means differences between particular locations which are in most cases insignificant. Based on this we can conclude that the location does not affect the basic density of spruce branch wood with bark.

*Table 2: Basic density of Norway spruce branch wood with bark from ten locations in the Czech Republic (μ – mean, SD – standard deviation, CV – coefficient of variation)*

| Location (forest type) | Number of branches | Number of samples | Basic density μ kg/m³ | SD kg/m³ | CV % |
|---|---|---|---|---|---|
| 1 (4B1) | 6 | 53 | 517.45 | 11.88 | 16.71 |
| 2 (5M1) | 6 | 65 | 506.46 | 11.03 | 17.56 |
| 3 (5K1) | 6 | 69 | 510.88 | 8.90 | 14.47 |
| 4 (5B1) | 6 | 66 | 527.11 | 9.97 | 15.37 |
| 5 (5F1) | 6 | 70 | 510.64 | 8.87 | 14.54 |
| 6 (5O1) | 6 | 59 | 495.95 | 8.52 | 13.20 |
| 7 (6M3) | 6 | 58 | 541.49 | 8.32 | 11.70 |
| 8 (6K2) | 6 | 62 | 513.21 | 9.51 | 14.59 |
| 9 (6F1) | 6 | 64 | 512.70 | 8.45 | 13.18 |
| 10 (6O1) | 6 | 58 | 512.78 | 9.40 | 13.96 |

*Table 3: Significance of differences in arithmetic means of basic density for spruce branch wood with bark in ten locations of the Czech Republic (statistical differences: (-) insignificant, (+) significant, (++) highly significant)*

| | 1 (4B1) | 2 (5M1) | 3 (5K1) | 4 (5B1) | 5 (5F1) | 6 (5O1) | 7 (6M3) | 8 (6K2) | 9 (6F1) | 10 (6O1) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 (4B1) | | - | - | - | - | - | - | - | - | - |
| 2 (5M1) | | | - | - | - | - | - | - | - | - |
| 3 (5K1) | | | | - | - | - | + | - | - | - |
| 4 (5B1) | | | | | - | + | - | - | - | - |
| 5 (5F1) | | | | | | - | + | - | - | - |
| 6 (5O1) | | | | | | | + + | - | - | - |
| 7 (6M3) | | | | | | | | + | + | + |
| 8 (6K2) | | | | | | | | | - | - |
| 9 (6F1) | | | | | | | | | | - |
| 10 (6O1) | | | | | | | | | | |

### *Basic density of branch wood*

Average values of the basic density of branch wood for individual locations including other statistic quantities are presented in table 4. The average basic density of branch wood is 576 kg·m$^{-3}$ (ranging from 570 to 593 kg·m$^{-3}$). Generally spoken, we can state that the differences of arithmetic means of the basic density of spruce branch wood between particular locations are statistically insignificant (Tab. 5). It means that the influence of the location on this property is not visible. The values of the coefficient of variation for individual sets are as follows: for the sets expressed by the arithmetic mean for individual branches the values range between 6.3 and 22.9 % (mostly 10–15 %), for individual locations 12.8–19.5 % and for the entire set of the Czech Republic it is 15.1 %.

*Table 4: Descriptive statistics of basic density of spruce branch wood in ten locations in the Czech Republic (μ – mean, SD – standard deviation, CV – coefficient of variation)*

| Location (forest type) | Number of branches | Number of samples | Basic density μ kg/m$^3$ | SD kg/m$^3$ | CV % |
|---|---|---|---|---|---|
| 1 (4B1) | 6 | 53 | 564.26 | 15.18 | 19.58 |
| 2 (5M1) | 6 | 65 | 584.43 | 11.57 | 15.96 |
| 3 (5K1) | 6 | 69 | 577.49 | 10.51 | 15.12 |
| 4 (5B1) | 6 | 66 | 592.67 | 11.83 | 16.22 |
| 5 (5F1) | 6 | 70 | 567.13 | 9.78 | 14.44 |
| 6 (5O1) | 6 | 59 | 572.73 | 10.09 | 13.54 |
| 7 (6M3) | 6 | 58 | 588.89 | 10.49 | 13.57 |
| 8 (6K2) | 6 | 62 | 562.96 | 10.87 | 15.20 |
| 9 (6F1) | 6 | 64 | 570.94 | 9.11 | 12.77 |
| 10 (6O1) | 6 | 58 | 572.64 | 10.62 | 14.13 |

*Table 5: Significance of arithmetic means differences in basic density of spruce branch wood in locations in the Czech Republic (- statistically insignificant difference, + statistically significant difference, + + highly statistically significant difference)*

| | 1 (4B1) | 2 (5M1) | 3 (5K1) | 4 (5B1) | 5 (5F1) | 6 (5O1) | 7 (6M3) | 8 (6K2) | 9 (6F1) | 10 (6O1) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 (4B1) | | - | - | - | - | - | - | - | - | - |
| 2 (5M1) | | | - | - | - | - | - | - | - | - |
| 3 (5K1) | | | | - | - | - | - | - | - | - |
| 4 (5B1) | | | | | - | - | - | - | - | - |
| 5 (5F1) | | | | | | - | - | - | - | - |
| 6 (5O1) | | | | | | | - | - | - | - |
| 7 (6M3) | | | | | | | | - | - | - |
| 8 (6K2) | | | | | | | | | - | - |
| 9 (6F1) | | | | | | | | | | - |
| 10 (6O1) | | | | | | | | | | |

### *Basic density of branch bark*

The basic density of branch bark ranges between 335 and 400 kg·m$^{-3}$ (average 364 kg·m$^{-3}$). The values of the coefficient of variation are as follows: for individual branches it was within 2.2–16.6 %, for individual locations 5.3–15.1 % and for the entire set of the Czech Republic it was 11.6 %. The coefficient of variation for most of the locations was below 11 %. Table 6 presents the descriptive statistics for individual locations. In contrast to the basic density of wood with bark and wood, the differences between individual locations in the basic density of branch bark were statistically significant or even highly significant (Tab. 7).

*Table 6: Descriptive statistics of the basic density of spruce branch bark in locations in the Czech Republic (μ – mean, SD – standard deviation, CV – coefficient of variation)*

| Location (forest type) | Number of branches | Number of samples | Basic density<br>μ<br>kg/m$^3$ | <br>SD<br>kg/m$^3$ | <br>CV<br>% |
|---|---|---|---|---|---|
| 1 (4B1) | 6 | 53 | 399.91 | 5.70 | 10.38 |
| 2 (5M1) | 6 | 65 | 336.00 | 5.07 | 12.17 |
| 3 (5K1) | 6 | 69 | 350.42 | 5.36 | 12.70 |
| 4 (5B1) | 6 | 66 | 366.88 | 4.71 | 10.42 |
| 5 (5F1) | 6 | 70 | 360.70 | 3.44 | 7.99 |
| 6 (5O1) | 6 | 59 | 334.93 | 3.09 | 7.10 |
| 7 (6M3) | 6 | 58 | 384.05 | 2.68 | 5.32 |
| 8 (6K2) | 6 | 62 | 395.13 | 7.59 | 15.17 |
| 9 (6F1) | 6 | 64 | 368.29 | 3.00 | 7.17 |
| 10 (6O1) | 6 | 58 | 357.17 | 3.16 | 6.73 |

*Table 7: Significance of arithmetic means differences in basic density of spruce branch bark in locations in the Czech Republic (- statistically insignificant difference, + statistically significant difference, + + highly statistically significant difference)*

| | 1 (4B1) | 2 (5M1) | 3 (5K1) | 4 (5B1) | 5 (5F1) | 6 (5O1) | 7 (6M3) | 8 (6K2) | 9 (6F1) | 10 (6O1) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 (4B1) | | + + | + + | + + | + + | + + | + | - | + + | + + |
| 2 (5M1) | | | - | + + | + + | - | + + | + + | + + | + + |
| 3 (5K1) | | | | + | - | + | + + | + + | + + | - |
| 4 (5B1) | | | | | - | + + | + + | + + | - | - |
| 5 (5F1) | | | | | | + + | + + | + + | - | - |
| 6 (5O1) | | | | | | | + + | + + | + + | + + |
| 7 (6M3) | | | | | | | | - | + + | + + |
| 8 (6K2) | | | | | | | | | + + | + + |
| 9 (6F1) | | | | | | | | | | + |
| 10 (6O1) | | | | | | | | | | |

### *Comparison of basic density of branch and stem wood*

The average values of the basic density of stem (at breast height) and branch wood from individual locations are presented in table 8. The average value of the basic density of the stem wood is 430 kg·m$^{-3}$. The difference in basic density between the maximum (location 1) and the minimum value (location 9) is 105 kg·m$^{-3}$. As far as the basic density of branch wood is concerned, the differences between individual locations are considerably lower (only 30 kg·m$^{-3}$). This shows that the variability in basic density of stem wood is higher than that of branch wood.

*Table 8: Arithmetic means of basic density of spruce stem and branch wood for ten locations in the Czech Republic*

| Location (type) | Basic density – kg/m$^3$<br>Stem | <br>Branches | <br>Difference |
|---|---|---|---|
| 1 (4B1) | 476 | 564 | 88 |
| 2 (5M1) | 446 | 584 | 138 |
| 3 (5K1) | 441 | 577 | 136 |
| 4 (5B1) | 428 | 593 | 165 |
| 5 (5F1) | 414 | 567 | 153 |
| 6 (5O1) | 446 | 573 | 127 |
| 7 (6M3) | 422 | 589 | 167 |
| 8 (6K2) | 436 | 563 | 127 |
| 9 (6F1) | 371 | 573 | 202 |
| 10 (6O1) | 419 | 572 | 153 |
| **Average** | **430** | **576** | **146** |

## Discussion

The data on density of spruce stem wood, are generally known and can be found in a wide range of literature. Also the variability of wood density and the factors affecting it were examined in many studies (e.g. Trendelenburg 1959, Janota & Kripeň 1960, Palovič & Kamenický 1961, Bernhart 1964, Kommert 1987, Petty et al. 1990, Grammel 1990, Zobel & Sprague 1998, Wagenführ 2000, Perstorper et al. 2001, Niemz & Sonderegger 2003, Kärenlampi & Riekkinen 2004, Gryc & Horáček 2007). However, the studies on density of spruce branch wood, wood with bark and bark and its distribution within branches are rare.

Our results show that the branch wood has a higher basic density than stem wood; the difference between these two densities is 88–218 kg·m$^{-3}$ (average for ten sites in Czech Republic is 146kg/m$^{3}$). Trendelenburg (1959) already stated that the density of dry spruce branch wood can be twice as high as stem wood density and that it can reach up to 900 kg·m$^{-3}$. Our data approximate these values. The individual values of the basic density of branch wood ranged namely between 330 and 920 kg·m$^{-3}$, the coefficient of variation for individual partial sets was 8.53–31.4 %. Such significant variability can be explained by the occurrence of compression wood, which is present in various amounts (abundant, moderate, or slight compression wood). The rule is that the basic density of branch wood decreases in the direction from the branch basis to its top; the greatest decrease was found in the first metre of the branch. Then the decrease is minimal. The data presented in literature indicate that the difference in density of the stem and the branch wood is related to wood species. For some species (or genera) the differences in wood density of stem and branches is small. The density of pine branch wood is only 430–570 kg·m$^{-3}$ (Timell 1986); the density of pine stem is 510 kg·m$^{-3}$ on average (Wagenführ 2000). Our density values of spruce branch bark (365 kg·m$^{-3}$) correspond quite well to basic density of spruce stem bark obtained for other regions (342 kg·m$^{-3}$, south-west Germany; 333 kg·m$^{-3}$, Switzerland), as presented by Dietz (1975).

No relationship between the basic density of stem and branches was found. There was also found no relationship among locations; the average values of the basic density of branch wood in various locations did not differ considerably. It means that the obtained values of the basic density of wood with bark (515 kg·m$^{-3}$) and the basic density of branch wood (576 kg·m$^{-3}$) can be used for any location within the Czech Republic.

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# Comparison of wood density in relation to growth rings of English oak and Sessile oak

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## Introduction

Oak trees cover 173 047 ha, i. e. 6.7 % of forest stands of the Czech republic. It is the second most important hardwood of the country (Report on the state of forest and forestry in the Czech republic 2007). There are three indigenous oak species in the Czech republic territory: English oak (*Quercus robur* L.), Sessile oak (*Quercus petraea* Matusch) and Downy oak (*Quercus pubescens* L.). The most important for forest and wood industry are *Q. robur* and *Q. petraea* (Pikula et al. 2003).

Wood density is one of the most important properties since it correlates well to many other physical and mechanical properties (Tsoumis 1991, Knapic et al. 2007). Thus wood density is a good feature for estimation of all other material properties. Wood density (or specific gravity) depends upon (1) the size of the cells, (2) the thickness of the cell walls, and the interrelationship between the number of cells of various kinds in terms of (1) and (2) (Panshin & de Zeeuw 1980). Wood density is not distributed evenly along the stem radius. Its distribution is related to the growth ring structure. Each growth ring consists of lighter earlywood and darker latewood. Latewood is made of cells which have thicker walls and smaller lumina in comparison to earlywood. This results in a higher density of latewood (Fromm et al. 2001) and explains why the density of wood increases with increasing proportion of latewood (Panshin & de Zeeuw 1980, Tsoumis 1991). Oak belongs to ring-porous hardwoods (Jane 1956, Schweingruber 1990) where an increase of growth ring width is associated with an increase of latewood proportion thus density also increases (Tsoumis 1991). According to decreasing ring width with an age of a tree it is obvious that higher density should be in the central part of a tree stem of ring-porous species.

The average value of oven-dry wood density by Kollman (1951) is 650 kg·m$^{-3}$ both for *Q. robur* and *Q. petraea*. Vichrov (1954) studied wood density of oaks at different locations. For flood plain forest he measured 589 kg·m$^{-3}$ and for downs 654 kg·m$^{-3}$.

As already as in 1973 Taylor et al. mentioned that variations in wood density are very important for wood industry. These data can be used to estimate intra-species and inter-species variation of the wood density and indicate variations available for selection in tree improvement programs. Finally, knowledge of wood density profile is likely to improve the accuracy of estimates of stem biomass.

Guilley et al. (1999) investigated wood density variation in *Q. petraea* and they proved that regional, site quality and silvicultural effects explained a very few part of the total variation of wood density. The consequence was that the relationship between wood density and radial growth did not change according to the sampled regions and according to the tree sampled site qualities (Guilley 2000). The hypothesis was stated that there was the same relationship between density and latewood proportion for two species of oak growing at their origin areas. This paper is focused on testing of this hypothesis.

## Material and methods

Sampling material was taken from two locations in the Czech republic, Europe. First location (1) was a floodplain forest stand of English oak (*Quercus robur* L.) near Útěchov at altitude 161 m a. s. l. and (2) lowland forest stand of Sessile oak (*Quercus petraea* Matusch) near Brno city, at

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altitude 440 m a. s. l. 5 trees from each location were cut and specimens 20 × 20 × 30 mm for density testing were prepared according to Fig. 1. Specimens with defects were removed. Specimens were dried at 103±2 °C in a program oven. Each ovendried specimen was measured in three anatomical directions and specimens were weighed. Oven-dry wood density of specimens was calculated as:

$$\rho_0 = \frac{m_0}{V_0},$$

where $m_0$ is the oven-dry weight and $V_0$ is oven-dry volume.
A set of 20 % of randomly selected specimens was used for calculation of average ring width (*arw*) and average proportion of latewood (*apl*). These values were calculated for each specimen of the set as:

$$arw = \frac{\sum_{x=1}^{n} w_x}{n},$$

$$apl = \frac{\sum_{x=1}^{n} l_x}{\sum_{x=1}^{n} w_x} \cdot 100\ (\%),$$

where $w_x$ is $x$-th growth ring width, $n$ is the number of rings on the specimen, $l_x$ is $x$-th growth ring width of the latewood.

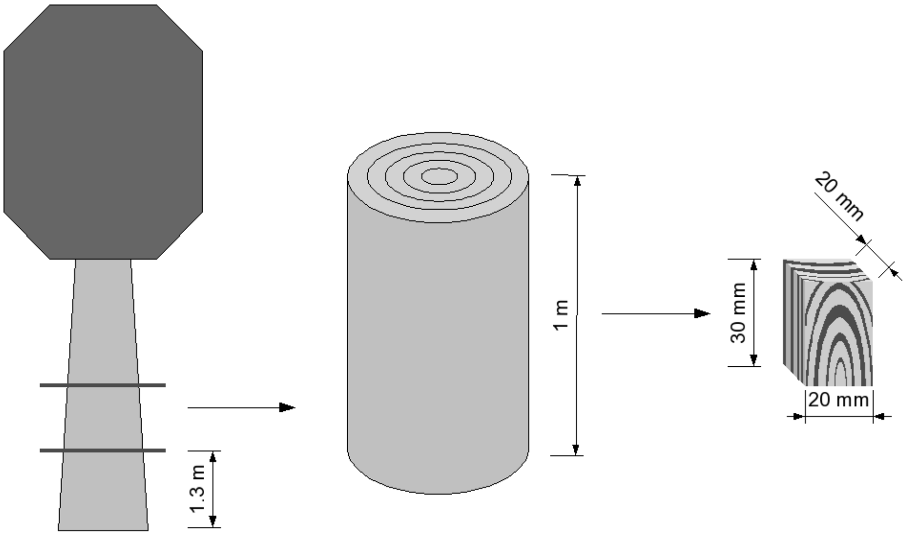

*Figure 1: Sampling: Tree – log – specimen.*

## Results and Discussion

*Q. robur* showed a lower average oven dry wood density (584.3 kg·m$^{-3}$) in comparison to *Q. petraea* (672.7 kg·m$^{-3}$), i. e. difference was 88.4 kg·m$^{-3}$ (Fig. 2). Variability of values was a little higher in *Q. robur* dataset (Tab. 1). The t-test proved that there was a statistically significant difference in mean values (α = 0.05).

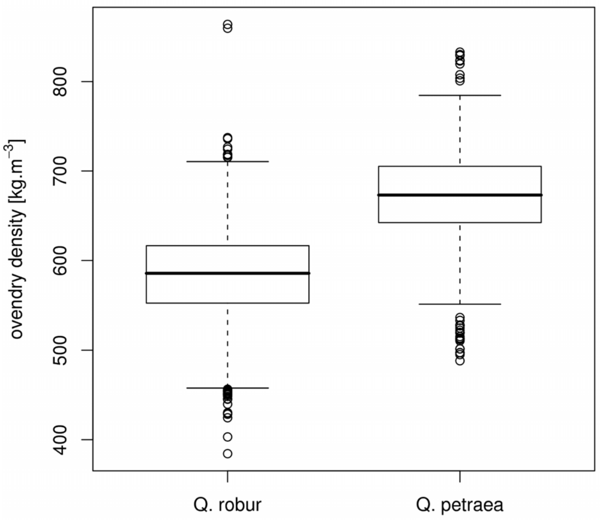

*Figure 2: Wood density – comparison of species.*

*Table 1: Oven dry wood density (kg·m$^{-3}$) of Q. robur and Q. petraea. Descriptive statistics.*

| | **N** | **average** | **Q1** | **median** | **Q3** | **min** | **max** | **std. dev.** | **CV (%)** |
|---|---|---|---|---|---|---|---|---|---|
| *Q. robur* | 1317 | 584.3 | 552.6 | 586.0 | 616.5 | 384.3 | 863.9 | 55.7 | 9.5 |
| *Q. petraea* | 822 | 672.7 | 642.4 | 673.1 | 705.2 | 488.2 | 832.9 | 52.5 | 7.8 |

As seen in Fig. 3 the wood density was distributed along the radius in very similar way in both species but values of *Q. petraea* were shifted higher. In both species the highest average value was detected in the central part of the stem diameter then average values decreased to the lowest one in the outer part of the stem. It is obvious that differences in wood density between centre and outer parts of the stem were lower in *Q. petraea*. Found out trends are in accordance with results of other authors (Vichrov 1954, Tsoumis 1991, Guilley et al. 1999)

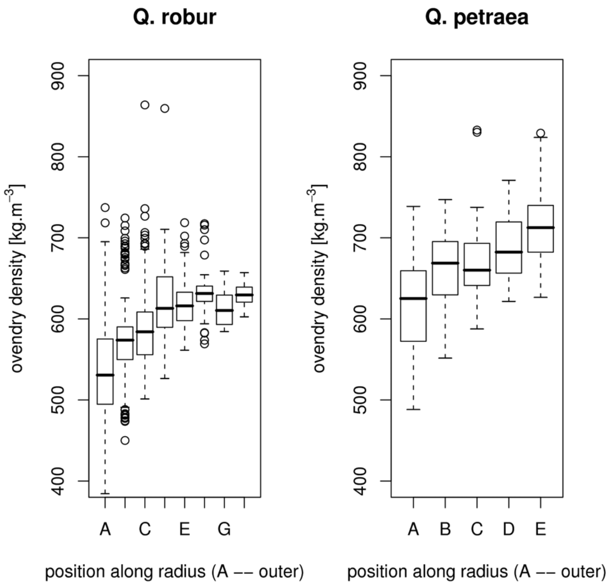

*Figure 3: Wood density distribution along the stem radius (A – close to bark, G – close to the pith).*

Figure 4 demonstrates differences in average values and variability of growth ring width in relation to species. The higher ring width was shown by *Q. robur* (2.1 mm) in comparison to *Q. petraea* (1.4 mm). The noticeable difference was in variability of these two files – values of ring width in *Q. robur* were almost twice variable as these in *Q. petraea* (Tab. 2).

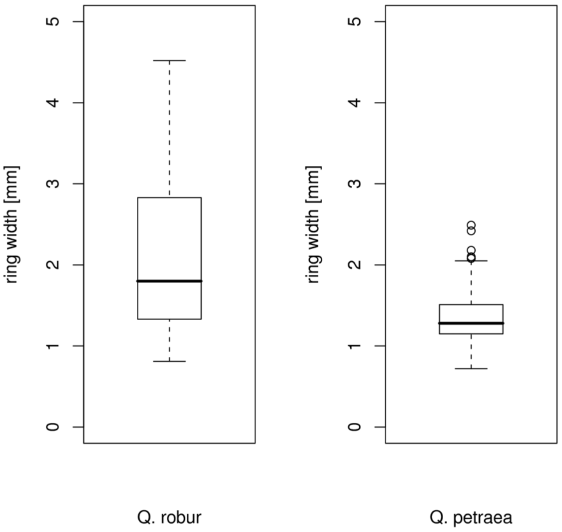

*Figure 4: Growth ring width*

*Table 2: Growth ring width (mm) of Q. robur and Q. petraea. Descriptive statistics.*

| | N | average | Q1 | median | Q3 | min | max | std. dev. | CV (%) |
|---|---|---|---|---|---|---|---|---|---|
| *Q. robur* | 289 | 2.1 | 1.3 | 1.8 | 2.8 | 0.8 | 4.5 | 0.9 | 45.0 |
| *Q. petraea* | 154 | 1.4 | 1.2 | 1.3 | 1.5 | 0.7 | 2.5 | 0.3 | 24.2 |

As seen in figure 5 average ring width decreased rapidly along the stem radius in direction from the pith to bark only in *Q. robur*. In *Q. petraea* files of ring width values for each radial zone were very similar. When compared to trends of density values (Fig. 3) there are differences especially in *Q. robur* part close to the pith and in *Q. petraea* it is an different trend along whole radius.

Distribution of late wood proportion in different zones along the stem radius is described in figure 6. Average values decreased along the stem radius in *Q. robur* but in *Q. petraea* values varied only a little. These trends along the radius are more similar to those for wood density.

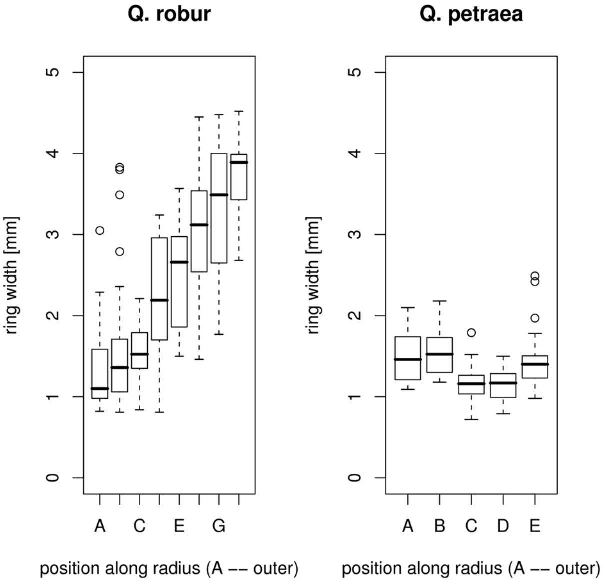

*Figure 5: Growth ring width distribution along the stem radius (A – close to bark, G – close to the pith).*

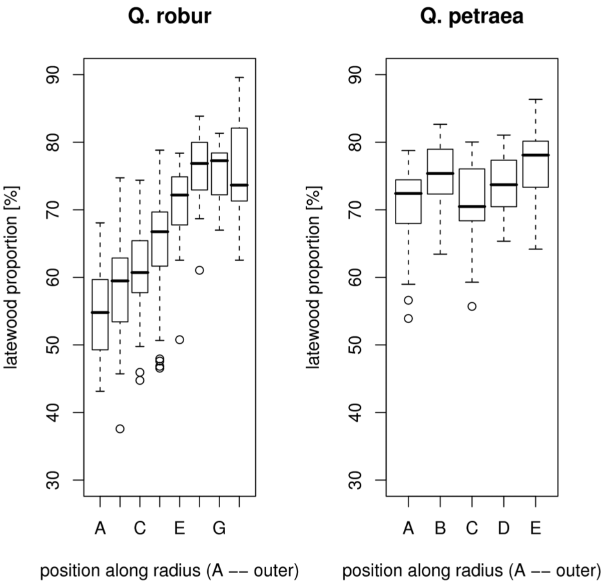

*Figure 6: Proportion of late wood distribution along the stem radius (A – close to bark, G – close to pith).*

Linear regression analysis of dependency between latewood portion and ring width showed that at the same ring width *Q. robur* produced lower proportion of latewood in comparison to *Q. petraea* (Fig. 7). Regression lines are quite parallel thus difference in theoretical values of latewood proportion is a constant. According to this it was supposed that it should resulted in lower wood density in *Q. robur* due to the rule that narrower rings have a lesser portion of latewood within a ring (Tsoumis 1991).

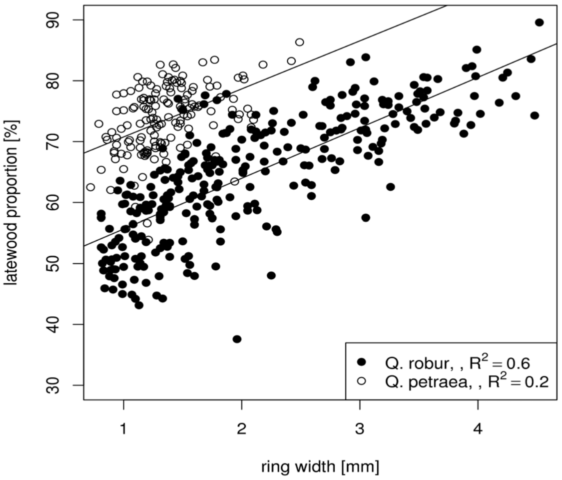

*Figure 7: Regression analysis of ring width and latewood proportion*

The suggestion was confirmed (Fig. 8). As seen in the figure – predicted (theoretical) wood density is higher in *Q. petraea* at the same growth ring width.

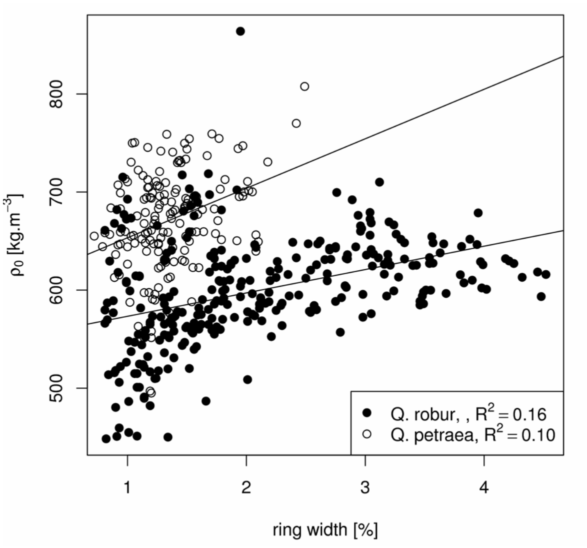

*Figure 8: Regression analysis of density and ring width*

As shown in figure 9 predicted values of wood density are higher in *Q. robur* until latewood proportion is smaller than 60 %. When it is greater than this value then predicted (theoretical) values of wood density are higher in *Q. petraea*.

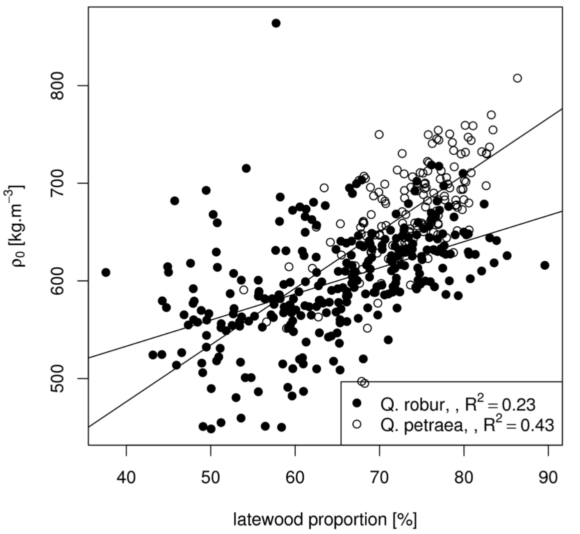

*Figure 9: Regression analysis of density and latewood proportion*

## Conclusions

It was proved that there were smaller differences in wood density between outer and inner part of the stem in *Quercus petraea* in comparison to *Qeurcus robur*. In other words difference between non-outlier range of min-max values in *Q. petraea* and *Q. robur* was 344.7 and 479.6, respectively. In spite of wider growth ring width of *Q. robur* the higher wood density was found out in *Q. petraea*. Both species were growing at their native locations, i. e. *Q. petraea* in downs and *Q. robur* in floodplain forest in lowland.

It can be concluded that:

1) at the same ring width *Q. petraea* had a higher latewood proportion
2) at the same ring width *Q. petraea* had a higher wood density
3) at the same latewood proportion (> 60 %) *Q. petraea* had a higher wood density

It is suggested that wood density is dependant not only on growth ring width and latewood proportion but it also depends on “quality” of latewood.

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