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Marieke van der Maaten-Theunissen,
Heinrich Spiecker, Holger Gärtner,
Ingo Heinrich, Gerhard Helle (eds.)

TRACE
Tree Rings in Archaeology, Climatology and Ecology

Volume 9

Proceedings of the DENDROSYMPOSIUM 2010
April 22nd - 25th, 2010 in Freiburg, Germany

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Preface

The 9th TRACE conference (Tree Rings in Archaeology, Climatology and Ecology) was organized by the Institute for Forest Growth, University of Freiburg, on April 22nd – 25th 2010 in Freiburg, Germany.

TRACE is an initiative of the 'Association of Tree-Ring Research' (ATR) and provides a scientific platform for young scientists, simultaneously maintaining a high scientific level.
Over 100 dendro-scientists participated at TRACE 2010, coming from Austria, Belgium, Bulgaria, Czech Republic, Estonia, France, Germany, Italy, the Netherlands, Norway, Poland, Romania, Russia, Slovenia, Spain, Sweden and Switzerland, among which 65 students.

A total number of 28 oral and 33 poster presentations highlighted the various aspects of tree-ring research: wood anatomy & seasonal dynamics, dendroecology & dendrogeomorphology, archaeology and climatology.
Two talks were presented by invited speakers. Philippe Rozenberg (INRA Orleans, France) introduced the concept of dendroplasticity. Wolfgang Beck (Johann Heinrich von Thünen Institute Eberswalde, Germany) showed the results of a German-wide research on the impact of drought and heat on tree- and stand vitality.

During the discussion forum, led by Achim Bräuning, several senior researchers discussed about the influence of data collection and data treatment on climate reconstruction with tree rings.

This volume of TRACE Proceedings contains 26 short papers and gives an overview of the wide spectrum of fields in tree-ring research.
We would like to thank the authors for contributing to this TRACE-volume, and the reviewers for their valuable comments on the manuscripts. The organizers of the conference also wish to thank the sponsors of TRACE 2010 – German Research Foundation (DFG) (Germany), Regent Instruments Inc. (Canada) and UMS München (Germany) – for their financial support.

Marieke van der Maaten-Theunissen
Heinrich Spiecker
Holger Gärtner
Ingo Heinrich
Gerhard Helle

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TRACE 2010 Conference, April 22nd – 25th, 2010, Freiburg, Germany

Organized by:
Institute for Forest Growth, University of Freiburg

SECTION 1

WOOD ANATOMY & SEASONAL DYNAMICS

Growth dynamics of *Podocarpus falcatus*

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Introduction

The tropical mountain forests in equatorial Africa are threatened by climate change and increasing land use intensity. In Ethiopia, the forest cover decreased during the last century to an alarmingly minimum. Recent remote sensing studies (Dessie & Kleman 2007) revealed a further reduction to 3% forest coverage in the vicinity of our study area due to an increasing population and expansion of agricultural land. On the other hand, additional environmental stress is caused by climate variability with a high frequency of drought events, possibly aggravated by long-term climate change. Therefore, understanding growth reactions and ecological behaviours of indigenous tree species to the changing environmental conditions are of great importance for a sustainable utilization of the remnant natural forest.

During recent years, several dendroclimatological studies were conducted in Ethiopia working with different tree species and dealing with various problems. Gebrekirstos (2006) analysed stable isotopes of *Acacia* species of the savannah woodlands for a paleoclimatic reconstruction and later assessed climate-growth relationships (Gebrekirstos et al. 2008, 2009). Furthermore, wood anatomical investigations of the highland species *Juniperus procera* showed clear distinct ring boundaries or faint to indistinct ring boundaries including many wood anatomical anomalies like wedging rings, causing serious constraints for cross-dating (Couralet et al. 2005, Sass-Klaassen et al. 2008, Wils et al. 2009). This variable wood anatomy is the result of regional and temporal differences in seasonal rainfall patterns. So far, the dendrochronological potential of the indigenous *Podocarpus falcatus* was only explored on a species from South Africa. February and Stock (1998) stated that the evergreen conifer tree is not useful for dendrochronological analyses because of its lobate growth and multiple rings. On the other hand, different species of Podocarpaceae (e.g. *Podocarpus totara*, *Podocarpus hallii*) were successfully analysed and crossdated in New Zealand (Bell &Bell 1958, Dunwiddie 1979, Norten et al. 1987).

Hence, the objective of our study is to investigate native Podocarpaceae in Ethiopia and check its dendrochronological potential. In this extended abstract we present first results of varying approaches to collect knowledge about the growth dynamics of *Podocarpus falcatus*.

Material and Methods

The study was conducted in the Munessa-Shashamene Forest, which is located on the eastern escarpment of the Main Ethiopian Rift Valley, 240 km south of Addis Abeba (7°26`N 38°52`E). The remnant natural forest covers an area of about 23.000 ha in the mid-highlands (ca. 2300m a.s.l.) and is highly disturbed due to selective logging by local people and due to cattle grazing. A bimodal climate pattern is characterized by an unreliable short rainy season from March to May and a long rainy season from July to September. Climate data collected close to the study site indicate an average annual rainfall (mean of 2006-2008) of 1121mm and annual mean temperatures of 15°C. In addition to *Podocarpus falcatus*, other indigenous tree species can be found: *Juniperus procera* (evergreen coniferous species), *Syzygium guineense* and *Prunus africana* (evergreen broadleaved species), *Croton macrostachyus* and *Celtis africana* (deciduous broadleaved species). Since March 2008, electronic point dendrometers (Ecomatik, Germany) registered stem diameter changes in 30 minute intervals that mainly result from variations of the tree's water status. From the original dendrometer data, daily radial change (dR) of the stem diameter is calculated from the difference between two consecutive daily stem diameter maxima. Increment cores and stem disks were collected for ring-width analyses (Lintab System, Rinntech, Germany) and high frequency density measurements (LignoStation, Rinntech, Germany). Furthermore, wood microcores were extracted with a trephor microcorer (Rossi et al. 2006). After embedding the wood samples in polyethylenglycol (PEG) or Paraffin, microsections of 10-30µm thickness were cut with a rotation microtome (Leica, Germany) and stained with solutions of astra blue and safranin red to distinguish living and lignified cells.

Local temperature, precipitation and air humidity were measured less than 0.5 km from the study site at 30 minute intervals. Vapour pressure deficit was calculated from the saturation vapour pressure of the air minus the actual saturation vapour pressure according to Häckel (1993).

Results

The old individuals of the up to 40 meter high *Podocarpus falcatus* are characterized by a complicated and winding lobate stem form (Fig. 1). The wood anatomical structures of *P. falcatus* are depicted in Figure 2. The coniferous tree generates quite distinct ring boundaries in the form of rather narrow bands of tracheids with slightly thickened latewood cells. Furthermore, pronounced intra-annual density variations within the earlywood, closely located to the former growth ring boundary, are found. These “false rings” were not formed annually and are sometimes difficult to differentiate from growth ring boundaries. The lobate stem growth causes wedging and missing rings resulting in serious constraints for crossdating.

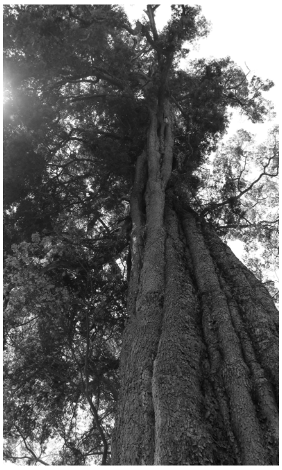

Figure 1: P. falcatus, the conifer tree can reach heights up to 40 meter with a stem diameter up to 2.5 meters. Stems of older trees are characterized by a lobate growth.

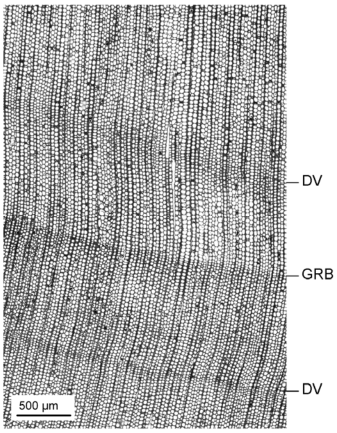

Figure 2: Wood anatomical structures of Podocarpus falcatus. The tentative growth ring boundaries (GRB) are formed by slightly thick-walled latewood cells. Intra-annual density variations (DV) can be found within the early wood cells.

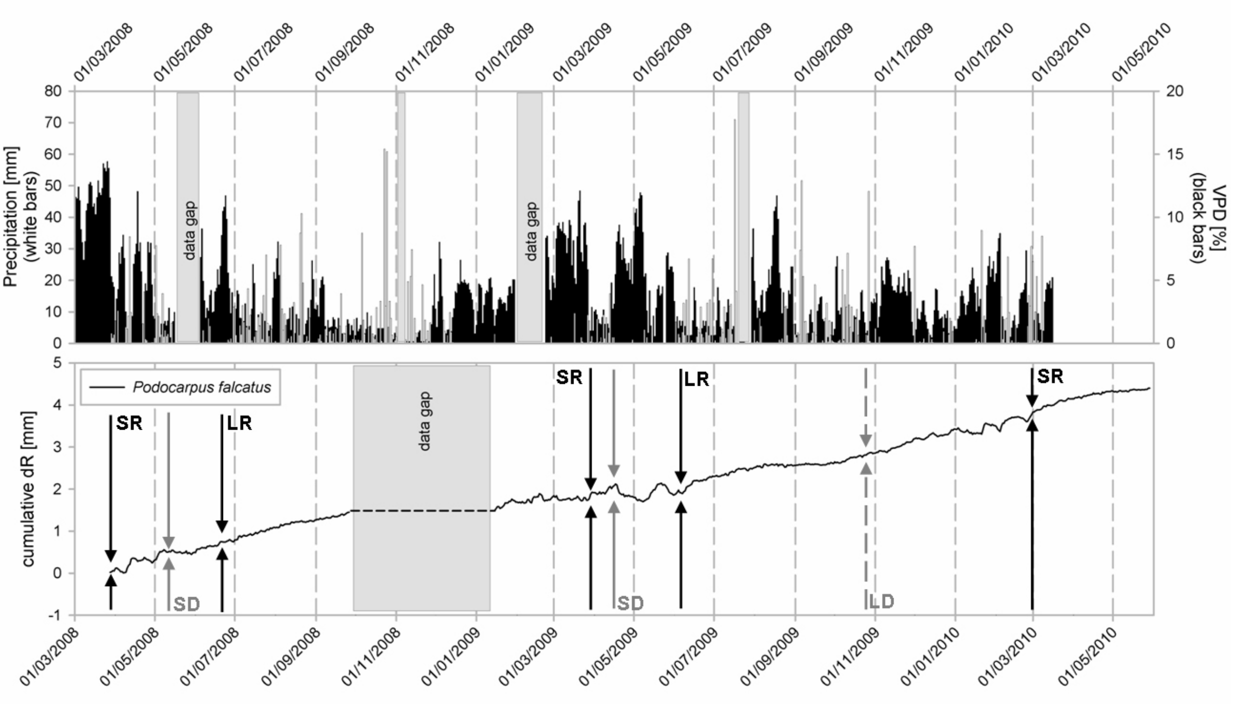

Figure 3: Climate data (precipitation and vapour pressure deficit VPD) and cumulative radial diameter change of evergreen conifer Podocarpus falcatus from March 2008 to May 2010. The black arrows indicate the rise of the dendrometer curve corresponding to the onset of the short rainy season (SR) and long rainy season (LR). The decrease of the dendrometer curve is initiated by the short dry season (SD) marked with grey arrows. Unfortunately, a data gap occurred during the long dry season of 2008 in the dendrometer data. However, data points before and after the data gap show the same value, suggesting cambial dormancy during dry season. On the other hand, the long dry season of 2009 (grey dashed arrow) was interrupted by many rain events causing a continuous increase of the stem diameter.

The dendrometer and climate data are shown in Figure 3. The tree reacts on rain events with an increasing stem diameter. During the short rainy seasons (SR) of 2008, 2009 and 2010 the stem diameter increased, and decreased again due to no or low precipitation during the short dry season (SD). With the onset of the long rainy season (LR) the dendrometer curve increased again. Unfortunately, because of missing data we can not exactly delimit the growing period during LR in 2008. However, the stem diameter before and after the data gap (grey box with dashed line) shows almost identical values implying no further cambial activity during the data gap. So, we would determine the end of radial growth season to occur around the beginning of the long dry season in October 2008. In contrast, the LR of 2009 lasted until the end of October followed by an indistinct LD with a rather dry November and major rain events since December. Consequently, stem diameter increased continuously until January 2010.

However, dendrometer data alone do not indicate whether the stem diameter increases is due to stem swelling and water uptake or due to cambial activity and wood formation. Hence, we additionally analysed thin sections of microcores (Fig 4) showing the cambial part of the stem. All samples show growth ring boundaries formed during the LD of the years 2007 and 2008. The distinctness and the width of the tree rings vary between the samples due to different growth patterns in tangential direction around the stem. In March 2009, the cambium was active during the SR and first wide cells were formed resulting in stem diameter increment (Fig 3). Thus, an intra-annual density variation is visible in the following samples caused by a second short dormancy of the cambium during the SD in April and May 2009. After the onset of the LR in June 2009, the thin sections of June, August and September show bands of freshly formed unlignified cells. Thereafter, cambial activity normally should cease with the beginning of the LD. However, after a dry November 2009 there were many rain events during the dry season of 2009/2010. Thus, favourable growth conditions continued. The thin sections witness ongoing cambial activity in December and a lack of a distinct growth ring boundary in the following samples of 2010.

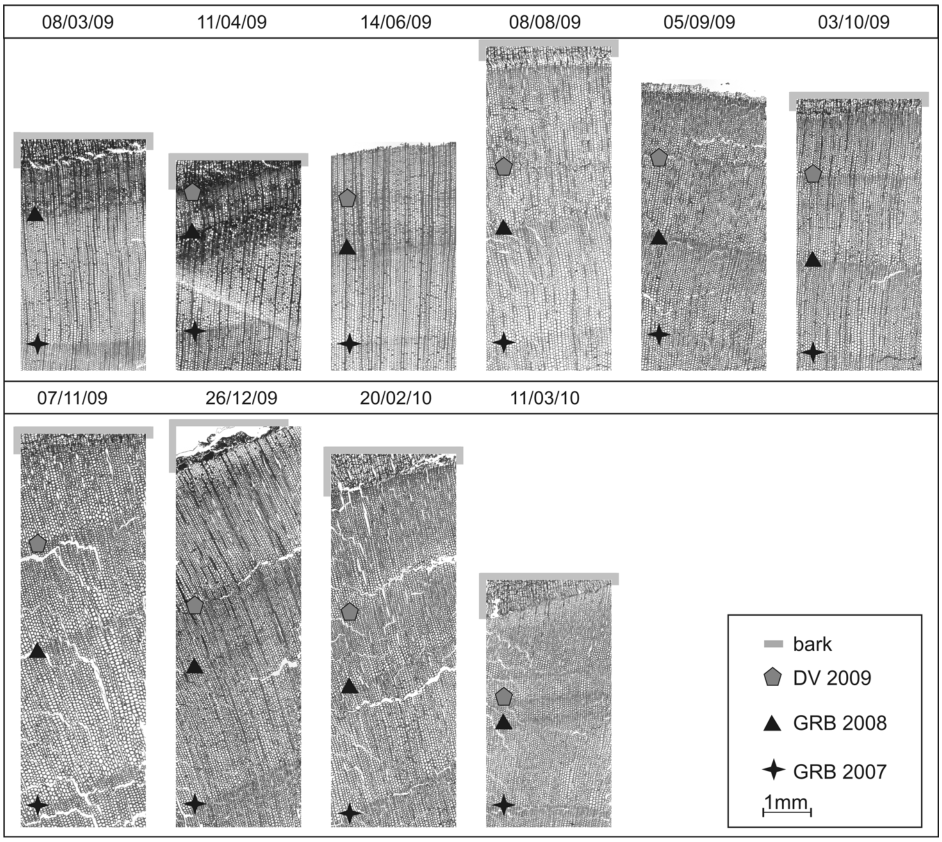

Figure 4: Thin sections of P. falcatus microcores extracted at different dates for detecting cambial activity. The symbols mark growth ring boundaries (GRB) and intra-annual density variations (DV) of the different years. Unfortunately, in greyscale the active cambium is difficult to recognize, but we determined that the samples of March 09, June 09, August 09, September 09, December 09 and March 10 are marked with fresh and wider cells. Furthermore, the varying number of cell rows in between the samples depends on the irregular and lobate stem growth of P. falcatus.

Discussion

Dendrometer measurements and wood anatomical samples complement each other in a useful way. As outlined above, stem diameter change may correspond to water uptake after rain events. Thus, the cumulative radial diameter change can not unambiguously represent cambial growth. An additional look on the microcores helps determining the period of active cambium. We conclude that *P. falcatus* reacts on sufficient rain events with an activation of the cambium at any time of the year. This growing potential was also found for the exotic conifer tree *Pinus patula* planted by the local forest enterprise. On the other hand, the broadleaved trees, e. g. *Celtis africana* or *Prunus africana*, are not able to interrupt their dormancy due to rain events (even during SR), but reactivate their cambium with the onset of the LR (Krepkowski et al. 2011).

Although there was no indication for an active cambium, a zone with ongoing cell division, in the microcores (Fig 4) and no precipitation in November 2009 (Fig 3), the stem diameter of *P. falcatus* was increasing. This reaction is caused by the further maturation of the cells, especially the enlarging and secondary cell wall thickening of the xylem cells lasting up to one month longer after the cambium stopped activity (Deslauriers et al. 2009).

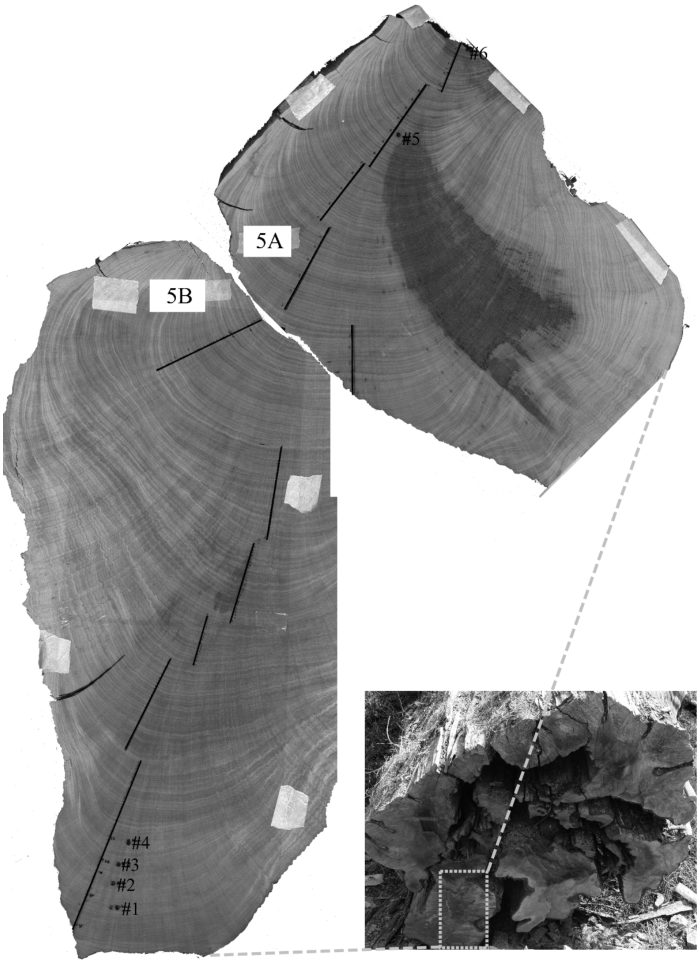

Figure 5: Total cross section and two stem disks of P. falcatus (5a/5b) with measurement paths from inner to outer part (top to bottom) for Lintab System. Wood density was measured on the backside of the disks along the same paths. Additionally six sampling points for ^{14}C-dating are marked.

While our studies indicate that the formation of annual growth ring boundaries of *P. falcatus* is variable, we conducted first ring width measurements on two stem disks of a fallen *Podocarpus* tree (Figs. 5 and 6). After a visual differentiation between growth ring boundaries and intra-annual density variations due to the distinctness and quantity of the latewood cells, we measured 372 tree-rings on the two disks. In contrast, the measurement of wood density and the subsequent calculation of growth ring boundaries yielded 353 tree-rings. For an additional testing of the annual nature of the detected growth ring boundaries and the rsulting age determination of the samples, we commissioned the ^{14}C-dating of selected rings (Fig 5) that according to ring counts should postdate the mid-1960 radioactivity peak and that predate the ^{14}C-plateau lasting until around A.D. 1650. These results should enhance our understanding of the dendrochronological potential of *P. falcatus*.

Moreover, to proof the annual nature of growth rings in *P. falcatus*, our further work will include the analysis of additional stem disks and increment cores with multiple sampling within and between trees and species. The microcoring of trees shall be continued over several vegetation periods to analyse the inter-annual variation of climate parameters and their impact on growth boundary formation.

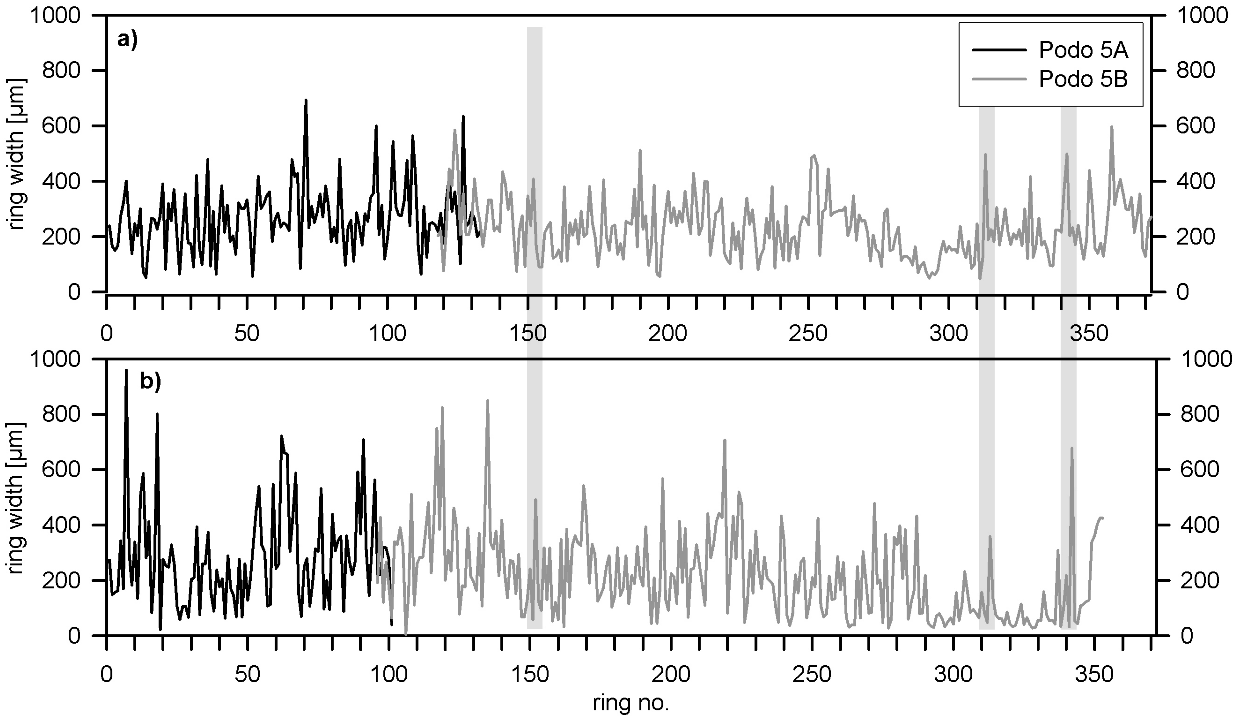

Figure 6: Tree-ring width of two overlapping P. falcatus stem disks (5A/5B) from pith (left) to bark (right). The overlap of the stem sections includes 20 tree-rings.

a) Growth ring boundaries identified visually and measured with a Lintab System.

b) Growth ring boundaries calculated by LignoStation due to max. wood density.

Similar results between measured (a) and calculated (b) growth ring boundaries are marked in grey.

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Radial stem growth of *Tabebuia chrysantha* (Bignoniaceae) in Southern Ecuador

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Introduction

In comparison to temperate and boreal climate zones and subtropical mountain environments, only sparse tree-ring information is available from tropical mountain regions. Studies on tree rings in tropical South America were carried out by Detienne (1989), Jacoby (1989), Vetter and Botosso (1989), Boninsegna et al. (1989), Borchert (1998), Stahle (1999), Wimmer and Vetter (1999), Justiniano and Fredericksen (2000), Worbes (2002); Brienen (2005), Schöngart et al. (2004), Kolb and Joly (2009). A serious constraint for tropical dendroclimatology is the fact that due to the lack of climatic seasonality most tropical tree species do not form distinct anatomical growth boundaries. Here, we introduce a tree-increment study derived from *Tabebuia chrysantha* growing in a humid tropical montane rainforest and in a tropical dry forest in Southern Ecuador. *T. chrysantha* (*Bignoniaceae*) is a broadleaved deciduous tree species with a height of up to 20 m. The wood is characterized by its hardness and high durability which makes *T. chrysantha* a tree species of high economic value (Gonzales et al. 2005, Sire 2001).

The first study site Reserva Biológica San Francisco (RBSF) is located in a tropical lower montane forest at the northern slope of the Podocarpus National Parc (3°58`S, 79°04`W) at ca. 2000 m a.s.l. (Bendix and Beck 2009). The slope descends to the valley of the Rio San Francisco which facilitates the inflow of humid air masses from the Amazon lowland into the eastern part of the research area. At the study site, the mean annual temperature is 15.5 °C and the average annual rainfall reaches 2176 mm with an additional input of ca. 120 mm water intake by fog (Emck 2007, Bendix et al. 2008). The region is characterized by a slight seasonality of rainfall with a wetter season during April to June and a drier season during October to December, when the generally very cloudy area receives higher amounts of solar irradiance which might lead to atmospheric water stress of the vegetation due to the high vapour pressure deficit (Bendix et al. 2008). During this season, a relatively dry period (‘Veranillo del Niño’) may occur in some years. The forests of the study area are a hotspot of biodiversity, hosting more than 180 tree species belonging to 53 plant families that form a canopy with a mean height of 20-30 m at the study site (Homeier 2004).

The second study site, the tropical dry forest, is located in the “Reserva Laipuna” between 575 and 1100 m a.s.l. at the south-west exposed slope of the Andes (4°12`S, 79°53`W). In this seasonally dry climate, temperature ranges from 11-21°C and shows no distinct seasonal variation. Average long-term annual rainfall is stated at 633 mm (Anuario Meteorológico INAHMI 1993). Since the beginning of our measurements in April 2007, annual rainfall averages around 800 mm. Rainfall is mainly limited to the time span between January and April/May. In some years, single rainfall events also occur in September.

Material and Methods

To study short-term stem diameter variations, we installed high resolution point dendrometers at a height of approximately 1.3 m on the tree stems. Since April 2006, measurements were taken in 30 min. intervals.

Results

The climatic conditions and the growth of *T. chrysantha* (one individual for each forest type) is shown in figures 1 and 2, respectively.

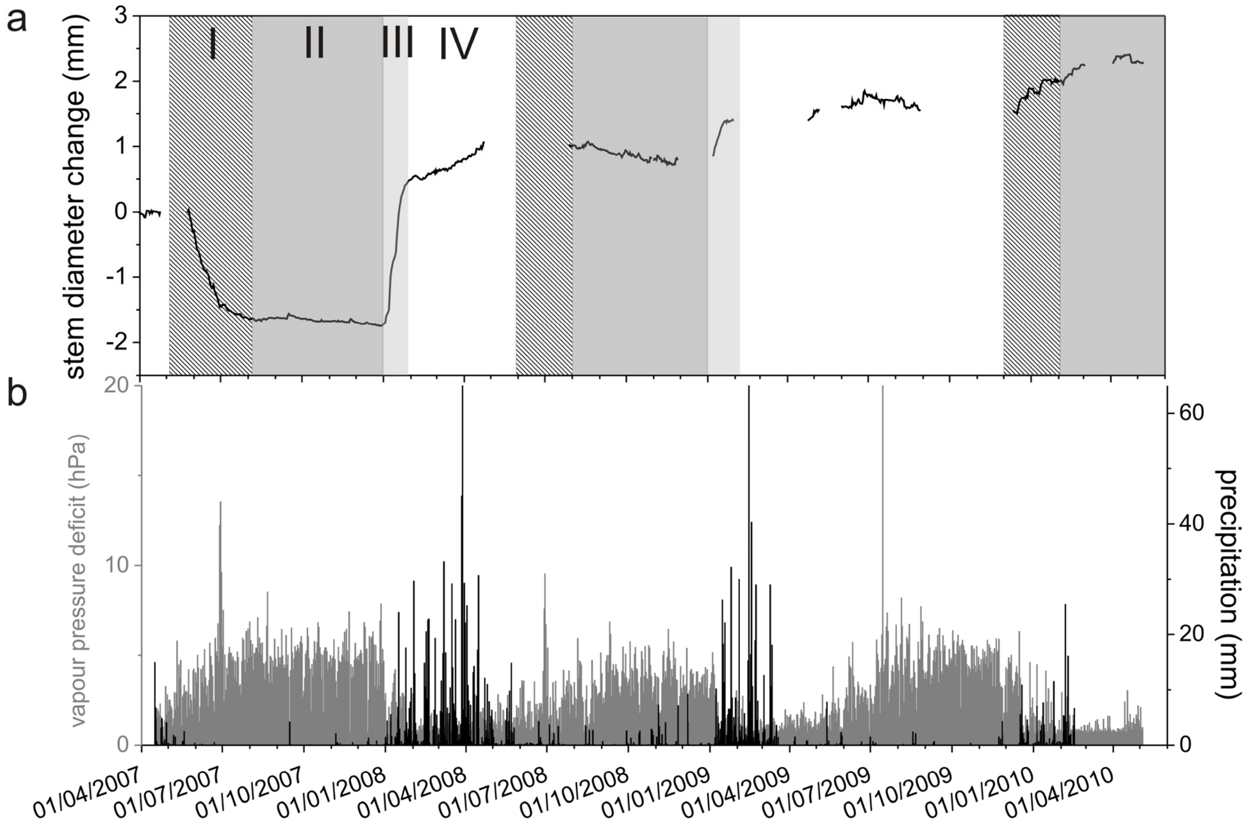

Figure 1: a) cumulative stem diameter changes from April 2007 to May 2010. b) daily sums of local precipitation and vapour pressure deficit during April 2007 to May 2010.

In the tropical dry forest (Fig 1), tree growth closely follows the annual course of moisture availability and can be divided into four distinct phases. In the first phase, at the beginning of the dry season in May 2007, while *T. chrysantha* was still foliated, the stem diameter decreased drastically. During the second phase, *T. chrysantha* began to shed its leaves. Conditions were dry with high incoming radiation, but single rainfall events caused short-term diameter expansions. The cambium was dormant and the stem diameter remained on a ‘plateau‘. At the onset of the cloudy, humid phase in January to April, *T. chrysantha* was still leafless. The rainfall caused rehydration of the stem to compensate for the shrinkage that had occurred during the preceding dry season. This process lasted around four weeks. During February to April, re-foliation and the resumption of cambial activity occured under humid conditions. The tree exceeded the maximum diameter of the previous year and showed net growth.

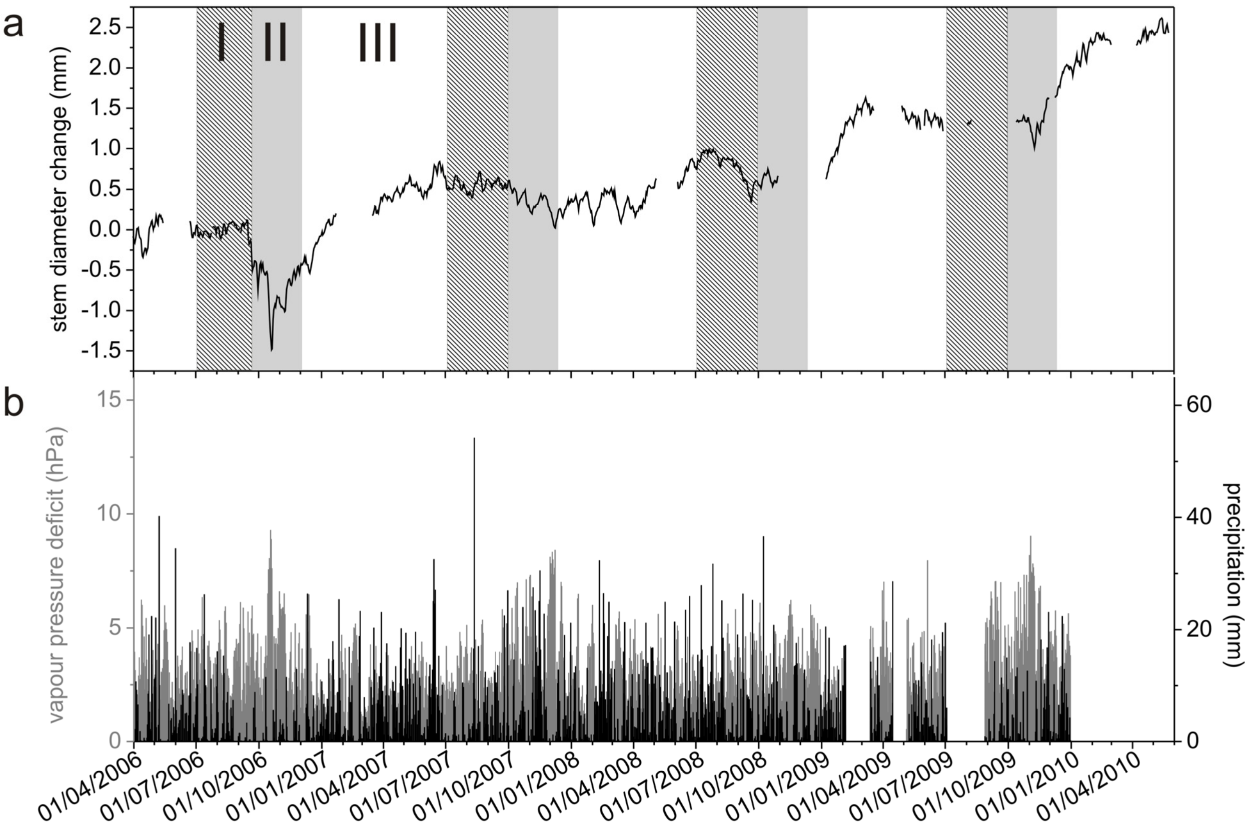

Figure 2: a) cumulative stem diameter changes from April 2007 to May 2010. b) daily sums of local precipitation and vapour pressure deficit during April 2007 to January 2010.

In the tropical mountain rainforest (Fig 2), the growth of *T. chrysantha* also reveals a seasonality of cambial activity, as indicated by the step-like appearance of the stem increment. At the beginning of July, *T. chrysantha* starts to shed its leaves. Cloudy, cool, and humid conditions prevailed and the stem diameter remained rather constant. During October and November, *T. chrysantha* re-foliated under less humid climatic conditions with lower cloudiness and higher incoming radiation. During this drier ‘Veranillo del Niño’ period, the stem diameter decreased. During December to June, *Tabebuia* was foliated and humid conditions prevailed. At this site, the trunks needed several weeks to exceed the pre-leafless stem diameter by active growth.

Beside seasonal growth dynamics, some inter-annual variations in tree growth can be related to climate variability, for example during the ‘Veranillo del Niño’ periods. In the middle of October 2006, nine consecutive rainless and sunny days were enough to initiate drastic stem shrinkage. The trunk needed several days to regain its diameter from the beginning of the ‘Veranillo del Niño’. In comparison, the stem diameter decreased only slightly during October/November 2007.

Discussion and Conclusions

Before carrying out tree-ring studies in tropical regions, a firm knowledge of seasonal tree growth dynamics and its control by climatic factors is necessary. This was achieved by the study of growth dynamics, especially of *Tabebuia chrysantha*, in the two different ecological forest types in the Ecuadorian Andes. These results are essential for the establishment of long tree-ring chronologies for climate reconstructions. *Tabebuia* trees form annual growth rings in both studied environments. However, the length of the active growth period varied between 3-7 months at RBSF and only 2-4 months in the dry forest (Fig 1 and 2). Interestingly, *T. chrysantha* shows a step-like appearance of stem increment and even shrinkage during the phases I and II in the lower montane forest. This is a clear indication for seasonal cambial activity, even in such a humid environment. A comparable behaviour was found for *Cedrela montana* (Meliaceae) (Bräuning et al. 2009).

In the tropical dry forest, *T. chrysantha* shows distinct annual cambial dynamics induced by the hydrological cycle. Periods of stem shrinkage and cambial dormancy occurred in the dry season (phase II). During phase III, stem increment occurred, which means that the stem is in a water saturated state (Delauriers et al. 2007).

Finally, to better understand the seasonal growth dynamics in relation to the local climate, we need to investigate long-term dendrometer measurements in relation to climate data. Additional analyses of stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes variation in wood cellulose of the studied trees will provide further information on the growth of *Tabebuia chrysantha*.

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SECTION 2

ECOLOGY & GEOMORPHOLOGY

Impact of drought and heat on tree and stand vitality – results of the study commissioned by the Federal Ministry of Food, Agriculture and Consumer Protection

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The onset of the so-called "drought study"

The extreme heat and drought of the summer 2003, especially in southern Germany and France attracted public attention. In all land use branches a serious worry arose about the future perspectives of natural production and its climatic bases. In April 2004, the Federal Ministry of Food, Agriculture and Consumer Protection commissioned the Institute for Forest Ecology and Forest Inventory in Eberswalde to conduct a study about the effects of drought and heat on the forests in Germany. First conceptual delibrations led to the assumption that own investigations in the fields of hydroecology and dendroecology are promising and necessary to generate data bases. The hydroecological investigations comprise the cause's side of the complex relationships between climatic impact, site properties and tree reactions, whereas the dendroecological investigations cover the effects side of these relationships. Time series of yearly growth rates are understood as proxy data of the current tree vigour (Dobbertin 2005). Subject of this contribution are the dendroecological investigations and results.

Material and methods

All investigations were conducted in close cooperation with the forest research institutes of the German federal states (Bundeslaender) at sample plots of the German Intensive Forest Monitoring Program (Level II). This program is a monitoring network of 88 case study sites consisting of typical forest ecosystems in Germany (Fig. 1).

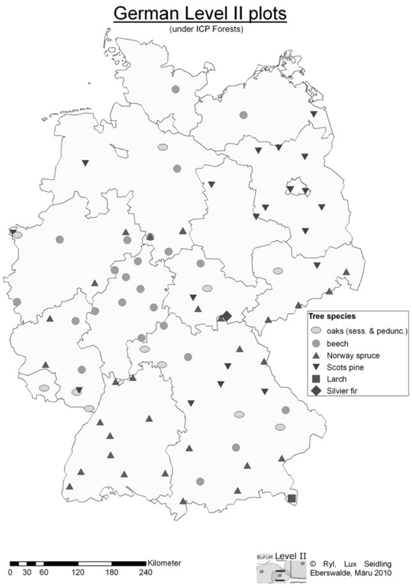

Figure 1: Spatial distribution of the Level II plots in Germany.

At all sample plots, data of water and element fluxes, deposition and climate are recorded as continuous time series. Data about crown condition, phenology and litterfall are collected as yearly values. The amount of growing stand volume is quantified by measuring diameters at breast height (dbh) and heights of all trees every fifth year. More detailed information may be obtained via "http://www.icp-forests.org/MonLvII.htm".

From this situation follows that real yearly growth rates for these Level II plots are not available. As a consequence, own dendroecological sampling and investigations were conducted. In the years 2005-2007, increment cores were taken to build up site chronologies for all German Level II plots. Cores were taken from at least 20 predominant und dominant sample trees of the main tree species (2 cores per tree). The preparation of the samples (drying, fixation, sanding) as well as ring width measurements and synchronization were carried out as following standard procedures. The total numbers of site chronologies per tree species include 33 chronologies for Norway spruce (*Picea abies*), 19 chronologies for Scots pine (*Pinus sylvestris*), 25 chronologies for common beech (*Fagus sylvatica*) and 11 chronologies for oak (*Quercus petrea et robur*), respectively.

The mean site chronology was obtained by application of a special method which ensures the bridging from dendroecology to forest mensuration and forest growth science (Beck, 2008). This procedure consists in the following main steps:

i: determination of the share of the inner part of the stems cross section, which is frequently missed by coring;

ii: derivation of a correction factor to eliminate errors caused by non-optimal boring direction, eccentric position of the pith and shrinkage of the increment cores during drying. The correction factor enables a standardisation of the tree ring widths in a way that the double sum of the corrected ring widths equals the diameter of the stem without bark. By this transformation the proportionality among the ring widths of a series is kept.

iii: Successive cumulation of the ring widths to obtain the course of diameter development; Calculation of the series of relative diameters by standardisation of the absolute diameter series to the final diameter without bark at the time of sampling;

iv: Calculation of series of mean relative diameter and their standard deviation; All series within a band of one standard deviation represent the growth course very well. Growth outliers deviating more than 2 standard deviations from the mean over at least a few decades can be clearly to identified and excluded from further analysis if necessary. In case that individual series are excluded, a recalculation of the mean series and standard deviation bands is necessary.

v: Calculation of the mean absolute diameter without bark at the time of sampling of all included trees. The series of mean absolute diameter growth course is derived by multiplication of the series of the relative dbh with this mean diameter. This mean series contains all information of the mean chronology. The mean ring width series is calculated by the differences of the mean dbh series year by year.

A decision about inclusion or exclusion of values is always based on the entire series and not on annual values. Doing so, the disadvantages of applying the Tukey's biweight robust mean may be avoided (Beck, 2008). Pre-whitening, trend estimation and elimination and indexation may be done in one of the many known ways. However, they have to be applied only once, namely to the mean ring width series. The corresponding parameters of these procedures may be stored, allowing to track the way from dbh via ring width (TRW) to tree ring index (TRI) also backwards: from TRI → TRW → dbh. In other words: The gaps between dendroecology and forest growth science are bridged.

Criteria for the evaluation of growth patterns

Growth trend interruptions and temporary trend deviations

A trend interruption is a sudden change of the average growth rate caused by singular external impacts or by a long-term change of growth conditions. The previous long-term growth trend is interrupted and growth is continues at a different level. Temporary growth deviations occur for a limited duration. The growth rates change more gradually and reverse back to normality in the long run. Temporary growth changes refer to medium term changes of growth conditions.

Disordered relations between first order autocorrelation (AR(1)) and sensitivity in ring width series

Among other parameters, first order autocorrelation AR(1) and sensitivity are used to characterize TRW-chronologies (e.g. Biondi, 1992, 2000; Di Filippo et al. 2007; Dittmar et al. 2003; Fritts, 1976; Piovesan et al. 2008; Wazny & Eckstein, 1991). AR(1) describes the strength of the relation between preceding and current ring widths. This relationship is very close if the growth course shows a clear long-term trend. When a growth course changes rapidly and frequently, autocorrelation drops down. In such cases, sensitivity is significantly inreased. The sensitivity parameter describes the strength of year by year changes within ring width series. Commonly, intense fluctuation of ring width is connected with high sensitivity, low autocorrelation and vice versa. AR(1) as well as sensitivity may be applied to entire time series or to subsections of time series of growth parameters. Combinations of significant autocorrelation and comparatively low sensitivity refer to balanced growth conditions without injurious impacts. In many cases AR(1) and sensitivity fluctuate irregularly within different subsections of a growth time series. This seems to be a normal pattern. A coincidence of a rapid increase of sensitivity exceeding the previous long-term range and a break down of autocorrelation is a strong indicator for stress conditions and harmful external impacts (Beck 2009).

Pointer years

Pointer years can be used to determine the effect of climatic conditions in single years. If the majority of all sampled trees of a stand or of a region show the same direction of growth reactions, the climate has the higher-ranking importance among all growth conditions. The method of pointer year analysis applied here requires a trend estimation by exponential smoothing of the TRW-series and subsequent indexation. The determination of pointer years is done without presetting of tree and stand threshold values. The index values of each tree at time step *t*, I_t, are transformed into relative growth deviations rGD_t by $rGD_t = 100 \cdot (I_t - 1)$.

The mean relative growth deviation mGD_t of all trees of the chronology and the corresponding standard deviation sGD_t is calculated for all time steps of the series. A year is decided to be a pointer year if $(mGD_t - sGD_t) \cdot (mGD_t + sGD_t) > 0$.

Growth reactions caused by the summer 2003

The course of the weather conditions during the summer of 2003 was the cause for conducting this study. Questions of special interest are the extent of immediate growth reductions in 2003 and the duration and the extent of the aftereffects on the growth course in the following years. To ensure a proximate comparability of growth reactions of various trees and stands, the absolute ring width values were transformed into relative ring widths with reference to the preceding five-year period 1998-2002

Climate – growth relationships

The existing tools to analyse relationships between climate and tree growth rates are based upon monthly values of climatic parameters (response functions according to Fritts 1976; state-space models by Visser and Molenaar 1988; bootstrapped response functions by Guiot 1991; evolutionary and moving intervals by Biondi 1997, Biondi & Waikul 2002). However, the climatic elements form a continuous series with seasonal properties without any monthly bounds. Within this continuous climatic series, those intra-annual time spans have to be found which are most closely related to the course and rhythm of tree growth.The method chosen consists in floating intra-annual time spans of variable width to find the best regression approach for describing climate–growth relationships (Beck 2007). The method performs an objectified variable selection based on daily data of temperature and precipitation. The technical implementation of these methods consists in the analysis tool CLIMTREG (climatic impact on tree growth). The newest release of this software may be obtained from the author.

Results

Indicators of disturbances

Growth trend interruptions, temporary trend deviations and disordered AR(1)-sensitivity relations were used jointly as diagnostic criteria to evaluate the normality or the size of disturbances in growth series. The assessment of the occurrence of disturbances was done by use of the mean radial increment and mean basal area increment series (Beck 2009). The share of disturbed growth courses related to the total number of chronologies per tree species was calculated (Fig. 2).

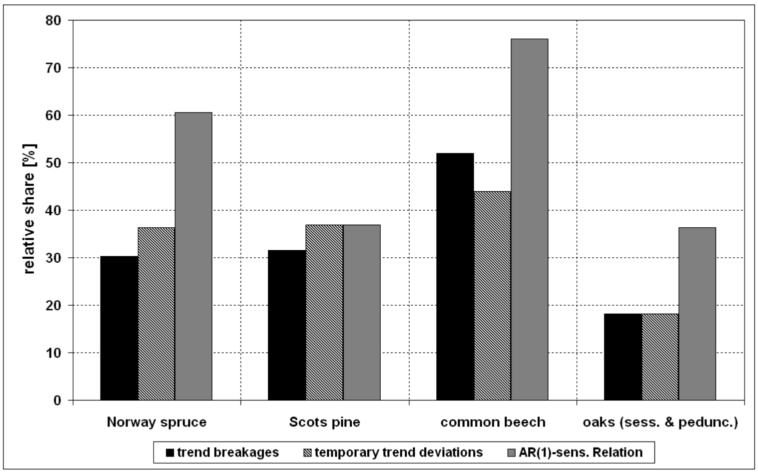

Figure 2: Frequency of the occurrence of disturbance indicators

Pointer years

Pointer year analysis was carried out for each site chronology, for peculiar regions of Germany and for the four main tree species as supra-regional, nationwide pointer years. The nationwide analysis included 650 spruces, 686 pines, 554 beeches and 209 sessile and pedunculate oaks within the common overlap interval from 1945 to 2006 (Fig. 3).

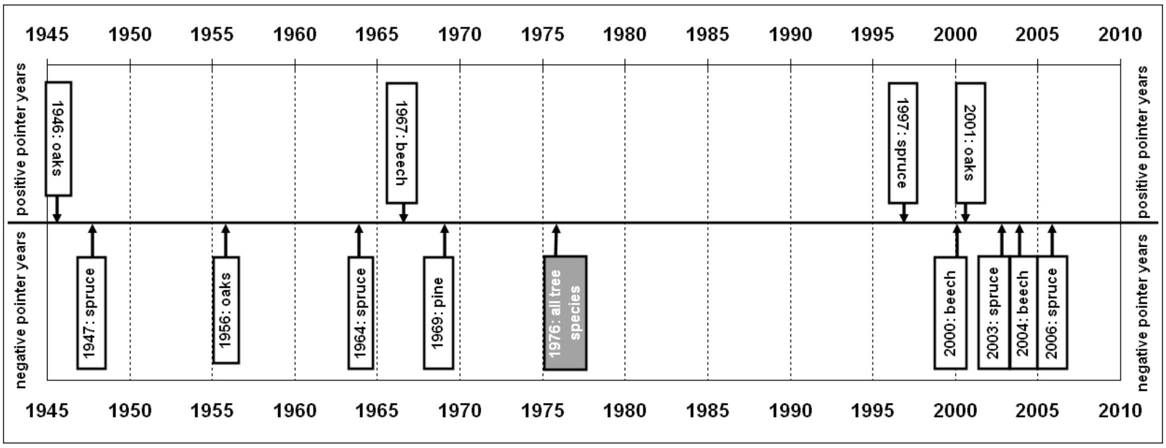

Figure 3: Nationwide negative and positive pointer years of the four main tree species in Germany. Growth reactions in the years from 2003-2006 are related to the reference period from 1998 to 2002.

The variations of mean relative ring width between 1998 and the year of sampling of all Level II plots of a tree species are displayed as cohorts of curves (Figure 4a-d).

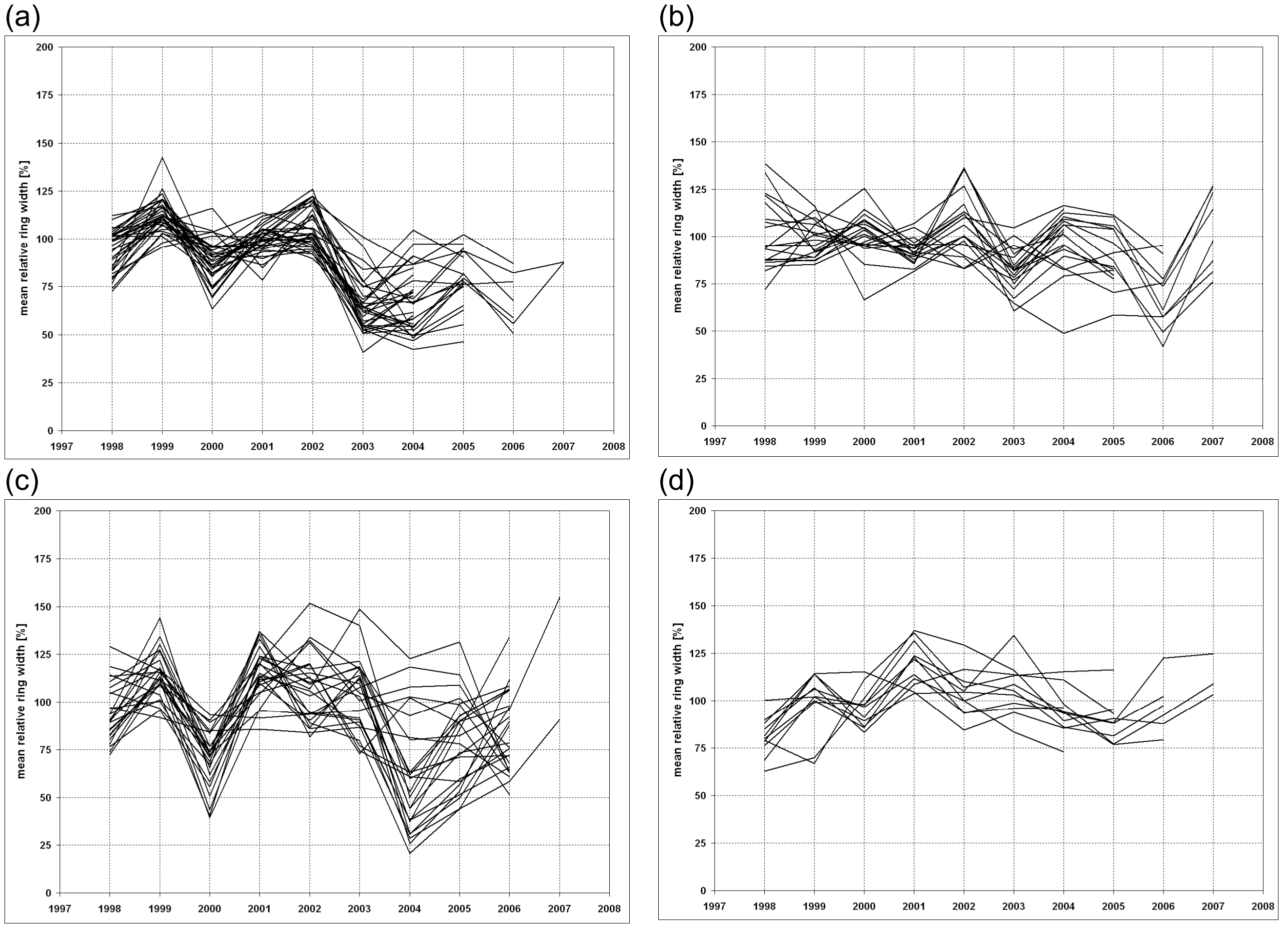

Figure 4: Relative mean ring width variations after 1998 of cohorts of (a) Norway spruce, (b) Scots pine, (c) common beech, and (d) sessile and penduncuIate oaks over all Level II plots over Germany.

Climate–growth relationships

The results of the investigations of the effects of climatic impacts on tree growth rates by application of the analysis tool CLIMTREG are manifold, according to the differentiation of the local climate within Germany, the tree species and the site properties. As an illustrative example, the analyses of 9 beech chronologies from central Germany (Hessen) were summarized (Fig. 5a-b). Current growth rates are predetermined by weather conditions of the preceding summer and autumn to a considerable extent. The influence of precipitation exceeds that of temperature.

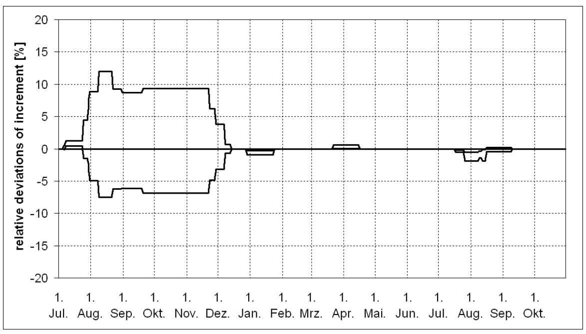

Figure 5a: Efficacy of the intra-annual temperature on the growth rate of common beech.

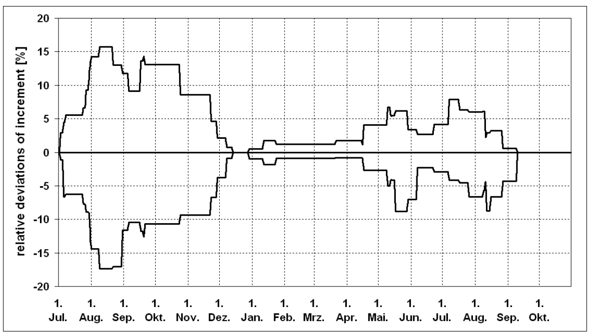

Figure 5b: Efficacy of the intra-annual precipitation on the growth rate of common beech.

This pattern of climatic efficacy is typical for sites where temperature is a not a growth-limiting climatic factor, different from the high-elevation or polar timberline.

Discussion

Disturbances within growth histories of trees as they appear as trend interruptions, temporary growth deviations and disordered AR(1)-sensitivity relations hint at an at least temporarily reduced vitality. Generally, increasing deposition of noxal and eutrophic substances up to a peak in the 1980s followed by more frequent extreme climatic impacts nowadays is considered as cause of such disturbances. However, the limits of buffering ability against external forces such as climatic impacts are still unknown. It has to be emphasised that all criteria for disturbances were found at living trees, which appeared physically undamaged at the moment of sampling. Nevertheless, considerable species-specific differences concerning the frequency of disturbances can be observed. Beech and spruce are more frequently affected than pine and oak.

Exceptional harmful or favourable climatic courses leave their marks as supra-regional negative or positive pointer years in tree ring series. The analysis of these pointer years of the four main tree species showed that there are more negative than positive pointer years. Harmful climatic impacts cause a uniform reaction of the majority of sample trees by withdrawal of resources or by exceedance of physiological thresholds. The recreation process, however, is less uniform among the individual trees. The appearance of pointer years is species-specific. Common pointer years of different tree species are extremely rare. The important exception is the year 1976 in which all main tree species were affected. A cold late winter and spring was followed by a hot and dry summer. Neither was the cold winter the coldest nor was the summer drought the driest among the extreme weather events, but the serial appearance of two harmful climatic impacts within one year resulted in an outstanding negative pointer year of the main tree species across most parts of Central Europe. After 1976, for a time span of 20 years, not a single pointer year occurred. Probably, other external forces superposed the effects of climate. Beginning with the year 2000 nationwide pointer years returned with a fast sequence of negative pointer years of beeches and spruces in 2000, 2003, 2004 and 2006.

The summer heat and drought in 2003 affected the tree species in a different manner. This concerns the intensity of the impact on the growth rate of 2003 as well as the duration of the aftereffects (Figure 4a-d). Norway spruce, which is the main tree species in Germany, was most harmfully affected by the deepest growth depression in 2003 and by the most enduring aftereffects. The growth courses of the investigated spruce stands show a very slow progress of recreation. Common beech, which is the most important broadleaved tree species in Germany, is affected by very sensitive growth depressions as well, but mostly with a delay of one year. However, the recreation progress is much faster than in that of Norway spruce. The pines react to the 2003 drought with prompt growth reductions but also with a fast recreation. Generally, pines exhibit a high degree of reactive elasticity or with other words, resilience. Sessile and pedunculate oaks tend to weak and inertial growth reactions. Seemingly, oaks dispose of a high degree of stress tolerance.

Quantified climate-growth relations for Norway spruce forests indicate a significant influence of climate on growth rates during summer and autumn of the previous year. In the German low mountain ranges, a continuous precipitation supply during the previous year as well as during summer of the current year is of greater importance than in mountainous south-western Germany, where precipitation is generally higher. In contrast to Norway spruce, climate during the current vegetation is of greater importance for Scots pine. In the dryer north eastern German lowlands, continuous precipitation supply from autumn of the previous year to the summer of the current year is of higher importance than in southern Germany. Similar to spruce, beech responds more strongly to climatic conditions of the previous than during the current year. In Hessen, which is the centre of the German beech distribution, a continuous precipitation supply up to the late summer of the current year is of higher importance than in western Germany.

Conclusions

Climate-growth relationships are modified by region, tree species and site properties The differences of growth reductions induced by the drought of 2003 are caused by the regionally different intensity of drought as well as by the different soil properties (water holding capacity) and additionally by the kind of adaptation of the tree stand to these site properties.

The shade tolerant tree species spruce and beech with higher requirements to soil and air humidity suffer more from drought events than pines and oaks. Especially, artificial spruce forests outside of their natural montane distribution range are highly endangered by drought and the subsequent attacks by bark beetles.

Up to the 1970s, winter coldness is a main cause of negative pointer years. During the last 20 years negative pointer years are mainly associated with summer heat and drought. Forestry and silviculture are confronted with changing climatic conditions for forest growth. The choice of tree species aiming at forest conversion measures should be decided very carefully, especially under conditions of limited precipitation supply. Results of dendroecological investigations comprising a number of regions, tree species and site properties are suitable to support forest decision making.

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Influence of drought on radial growth of Norway spruce in north-eastern Poland

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Introduction

The course of weather elements exhibits various pace and intensity over time and space, and therefore influences tree-ring formation in different ways. Ongoing climate change does and undoubtedly will affect growth of trees in great measure as climate is considered as the most influential natural factor that shapes this process (Saxe et al. 2001, Aitken et al. 2008, Mohan et al. 2009). Long-term scenarios, although still yet deficient and unsure, allow the assessment of the most probable climate conditions in the future. This, in turn, may serve in forecasts of forest development based on known relationships between tree growth and climate conditions, since factors that influence growth, productivity, mortality and germination of trees are responsible for the adaptation ability of forest ecosystems (Chmura et al. 2010).

According to even moderate scenarios (Christiansen et al. 2007, Meehl et al. 2007), temperature in Poland will rise by the end of the current century by 3-4°C depending on season. Although precipitation in that period will increase by up to 15% in some places, the total evapotranspiration will also rise and more droughts may occur (Hobbins et al. 2008). Together with overall poor water supply this may lead to deterioration of conditions of Polish forests including massive decline of tree species and reduction of forest cover. This drought-induced decline may especially affect species that are very vulnerable to moisture deficit, i.e. oak (Drobyshev et al. 2008). Norway spruce (*Picea abies* (L.) Karst.) is widely addressed as a species vulnerable to the moisture deficit, especially during the vegetation period (e.g. Solberg 2004, Vitas 2004). Summer droughts are sometimes identified as direct causes of extremely narrow tree-rings (negative pointer years). The response of trees to the limited amount of water may differ with regard to the habitat type. High moisture content in the soil may reduce unfavourable effects of low precipitation and high temperature. In turn, trees on drier sites may suffer significant decrease in growth or even stop growing under drought conditions. Recognition of these potential dangers is crucial from the point of view of forest economy.

The objective of this study was to investigate the influence of drought during the vegetation period on radial growth of Norway spruce in north-eastern Poland and to analyse the role of the moisture deficit in formation of significantly narrower tree-rings.

Material and methods

Material representing four habitat types was collected on 12 plots in three forest complexes in north-eastern Poland. At each plot, 15 dominant, healthy and undamaged trees were sampled. One increment core per tree was taken. The cores were sanded and scanned. CooRecorder image analysing program (www.cybis.se) was used for measuring tree-ring widths. CRUTS 2.1 database (Mitchell & Jones 2005) provided mean monthly air temperature and precipitation data. In total, 139 individual tree-ring width series were used to construct chronologies according to the conventional procedures (Cook & Kairiukstis 1990) with CRONOL software (Holmes 1999).

Residual chronologies were correlated with series of a simple moisture availability index (ratio between precipitation and temperature; the lower the index value, the drier conditions index describes) calculated for each month during the vegetation season (May-August) as well as with the total sum of precipitation in that period. DendroClim2002 (Biondi & Waikul 2004) software was

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used for correlation calculation. Negative pointer years defined as the situation when the majority of trees at an individual site formed a conspicuously narrower tree-ring were compared with the moisture surplus/deficit index calculated as a deviation of May-August sum of precipitation from the 1901-2000 mean.

Results

Growth of analysed spruces turned out to be strongly dependent on water conditions during the vegetation season. The strongest positive correlation between the moisture availability index and tree-ring width was found for June (Tab. 1). For the majority of the investigated sites this relationship was significant. In general, positive but not significant character of this relationship was also observed for May and July. In August, a surplus of available water does not favour growth of the analysed trees, but this relation was not statistically significant (Tab. 1). Similar pattern was found for correlation between ring width and total precipitation during May-August period. Again, almost all of the analysed chronologies exhibited significant positive correlation with water availability (Fig. 1). No clear the role of habitat type in modification of described relations was observed.

Table 1: Influence of water availability during the vegetation period on Norway spruce growth.

Month	**PA1**	**PA2**	**PA3**	**PA4**	**PK1**	**PK2**	**PK3**	**PK4**	**PR1**	**PR2**	**PR3**	**PR4**
correlation coefficients												
V	0,147	0,061	0,149	0,121	0,173	0,156	0,020	**0,372**	0,117	0,078	-0,153	0,136
VI	**0,379**	**0,307**	**0,351**	0,225	0,225	**0,248**	0,192	**0,296**	**0,408**	**0,285**	0,066	**0,392**
VII	0,177	**0,319**	0,282	0,194	0,062	0,258	-0,083	**0,237**	0,037	0,077	0,118	0,056
VIII	-0,026	0,132	-0,003	0,078	-0,019	0,047	-0,096	0,048	-0,077	-0,185	-0,068	-0,054
response function coefficients												
V	0,133	0,093	0,145	0,138	0,158	0,158	-0,008	**0,361**	0,079	0,019	-0,174	0,109
VI	**0,341**	**0,252**	**0,302**	0,180	0,190	**0,205**	0,170	**0,226**	**0,382**	**0,293**	0,096	**0,355**
VII	0,164	**0,232**	**0,253**	0,127	0,038	0,180	-0,039	0,135	0,066	0,153	0,135	0,072
VIII	-0,167	-0,065	-0,187	-0,035	-0,060	-0,070	-0,092	-0,054	-0,158	**-0,278**	-0,145	-0,148

PA – Augustowska Primeval Forest, PK – Knyszyńska Primeval Forest, PR – Romincka Primeval Forest; habitat types: 1 – fresh mixed coniferous, 2 – fresh mixed deciduous, 3 – swampy mixed deciduous, 4 – fresh deciduous forest habitat types; values significant at the 0.05 level were bolded.

For the 20th century, 8 individual (1906, 1912, 1931, 1941, 1954, 1964, 1992 and 2000) as well as one consecutive (1979-1980) negative pointer years of spruce in north-eastern Poland can be distinguished. A few pointer years coincide with water availability deficit (Fig. 2). Only 1964 turned to be a drought-induced pointer year observed in all three analysed forest complexes. However, in Romincka Primeval Forest it is not so profound. Interesting situation occurred in that forest complex in the years 1952-54, when rather poor increment coincides with three consecutive years of severe water deficit (Fig. 2, PR – panel). In turn, in Knyszyńska Primeval Forest, a narrow ring in 1984, which itself has average precipitation during May-August, is proceeded by two years of drought during the vegetation season.

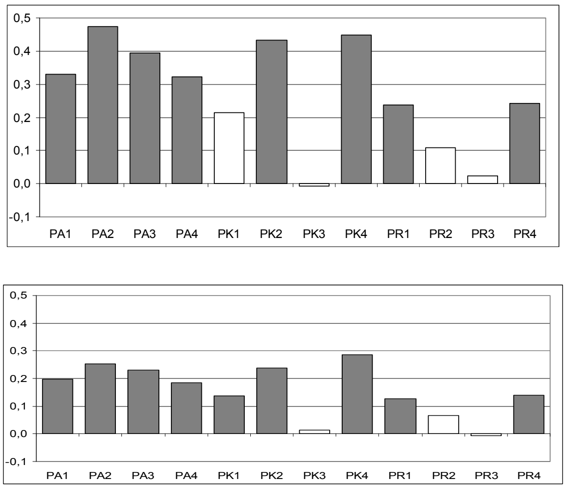

Figure 1: Influence of precipitation during the vegetation period on Norway spruce growth. Top – correlation coefficients, bottom – response function coefficients, grey bars indicate values significant at the 0.05 level. For site description see Table 1.

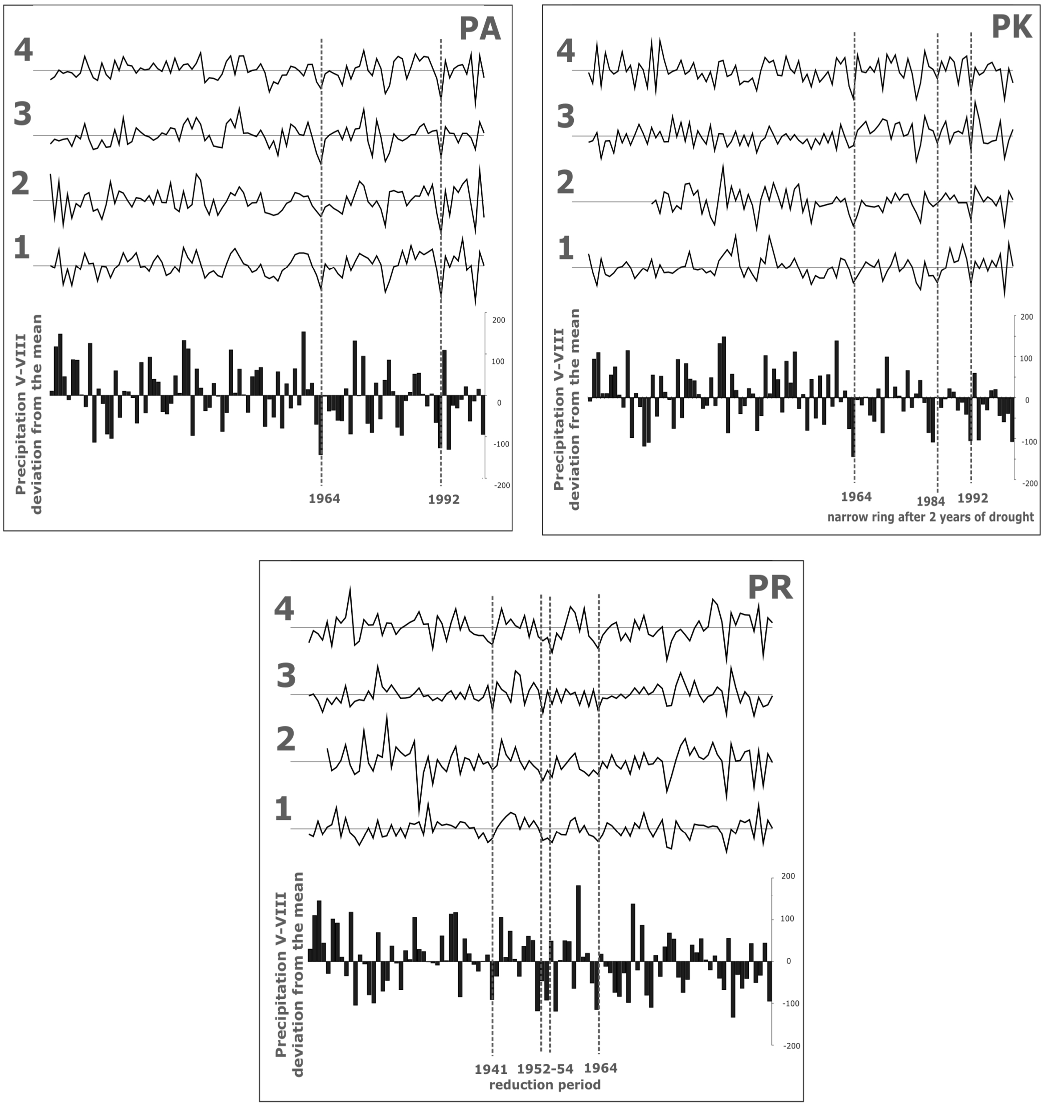

Figure 2: Comparison of Norway spruce growth (standard chronologies) and water conditions during the vegetation season in the 1901-2000 period. Vertical dashed lines indicate years when very narrow tree rings coincide with unusually low May-August precipitation. For site description see Table 1.

Discussion

Spruces in north-eastern Poland grow under average (not extreme) climate conditions and hence, in general, they do not respond very strongly to climate varaitions (Bijak 2007, 2010), which is in accordance with the concept presented by Mäkinen et al. (2003). However, ongoing climate change may alter this situation as weather may become more harsh. According to some of the available scenarios (e.g. Christiansen et al. 2007, Meehl et al. 2007), both precipitation and temperature in north-eastern Poland will rise, which may lead to increased evapotranspiration. This, in turn, may result in higher drought occurrence (Hobbins et al. 2008). Since Norway spruce is widely addressed as a species vulnerable to the moisture deficit, especially during the vegetation period (e.g. Zielski & Koprowski 2001, Solberg 2004, Vitas 2004, Čejková & Kolář 2009), such evolution of climate conditions probably will have negative consequences for growth of that species.

Analysed spruces showed significant response to low precipitation and high temperature in early summer (Bijak 2010). Similar observations were reported for north-eastern Poland by Koprowski & Zielski (2006), for neighbouring Lithuania by Vitas (2004) and for Belgium by Laurent et al. (2003). Present study reveals that overall precipitation during the vegetation season as well as moisture availability in the May-July period is very important for spruce tree-ring formation. Especially pluvial and thermal conditions in June turn out to be the most crucial and seem to be the main driving force for ring formation in the investigated spruces. Water deficit and warmth in late spring and summer increase the dehydration of the plant (Dittmar & Elling 1999). This, in turn, may cause restriction or even cessation of cambium activity and, as a result, xylem production.

Soil fertility and moisture conditions of the studied sites seem to have no prominent influence on the relationship between water availability and growth of the analysed spruces. No clear pattern indicating that specific habitat sharpens or softens the impact of drought can be noticed. Since no significant effect of habitat conditions on climate-growth relations was found for analysed spruces (Bijak 2010), other factor(s) must be important for climate-growth relationships. Drought vulnerability of spruce suggests that bedrock and hence, ground water table level might be such factors. This hypothesis can be supported by high correlation of growth rates with both the water availability index and May-August precipitation observed for Augustowska Primeval Forest sites (Tab. 1, Fig 1). These sites are located on sandy glacial outwash plain (sandur) originating form the last glacial period. This well permeable substrate may cause fast seepage of rain water that is not stored in the soil, and hence, is not available for trees.

Detected negative pointer years are, in general, similar to those found in natural, unmanaged stands of Białowieża National Park (Koprowski & Zielski 2008). Authors link most of the pointer years with low precipitation, especially in the May-July period. Despite of the observed dependence of analysed trees on moisture availability, a comparison of the occurrence of very narrow tree rings with drought events indicates that only a few negative pointer years are drought-induced (Fig. 2). This may suggest that although spruces in north-eastern Poland are vulnerable to poor water availability, they are able to resist most drought conditions. Such situation may be influenced by silvicultural treatments. Laurent et al. (2003) state that thinning improved the resistance of spruce stands from central France to drought. However, moisture shortage may affect trees in indirect ways. Drought may weaken a tree and make it more sensitive to the attacks of fungi or insects, which in turn may result in poorer increment in the current or in the following year (Rolland & Lemperiere 2004).

Conclusions

Spruces in north-eastern Poland exhibit similar radial growth patterns and generally uniform response to moisture availability during the vegetation period. The most important time in terms of water conditions is in June. Majority of analysed trees showed strong dependence on water deficit in that month. The habitat type did not influence the character of growth-drought relationship.

Only a few negative pointer years can be directly linked with water deficit during the whole vegetation period or with drought conditions in an individual month. However, even short-time moisture shortage may weaken a tree and make it more sensitive to the attacks of fungi or insects, which in turn may result in poorer increment in the following year(s).

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Long-term drought and streamflow variations in Turkey

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Introduction

For a variety of reasons, fresh water resources on the globe are becoming scarcer. The degree of water scarcity and its political, economic and social implications are felt more severely in regions like the Middle East. The Euphrates-Tigris river system is one of the major sources of water in the region (Kibaroglu 2002). The watershed of the River Euphrates lies within the boundaries of Turkey, Syria, Iraq, and Saudi Arabia. Almost 90% of the runoff from the basin is generated within the highlands of eastern Turkey as the result of snow-melt occurring during late spring and early summer. At this time, flood levels are usually reached along the whole length of the River (Beaumont 1978). Expanding cities are placing larger demands on water supplies. Thus, even moderate droughts may have major effects on meeting water demands. As droughts reoccur, interest reappears in evaluating the chances that conditions causing the emergency will recur (Phipps 1983). However, many drought and streamflow records in the east Mediterranean and in Turkey in particular are less than 50 years in length. Although such relatively short records are conventionally used as a basis for future planning, this record length appears to be too short to determine with enough confidence the true river flow frequency and the frequency and duration of droughts. Detection of long-term trends and possible cycles is impossible over short time periods, but may be feasible using long drought and streamflow series reconstructed from tree rings (Holmes *et al.* 1979). Because of the potential value of increased record length, it may be desirable to produce proxy records of drought and streamflow. This paper presents tree-ring reconstructions of drought for Southwest Turkey and of monthly spring streamflow in the Euphrates headwaters based on stable isotopes in tree rings of Juniper trees.

Material and Methods

The name of the study site is Jsibeli, situated in the Akdağlar mountains (~1800 m a.s.l.) near Elmali in the hinterland of the Antalya district (Fig. 1). The climate is typical Mediterranean with dry and hot summers and cool winters. The site is covered with snow from December to April (Türkeş et al. 2002).

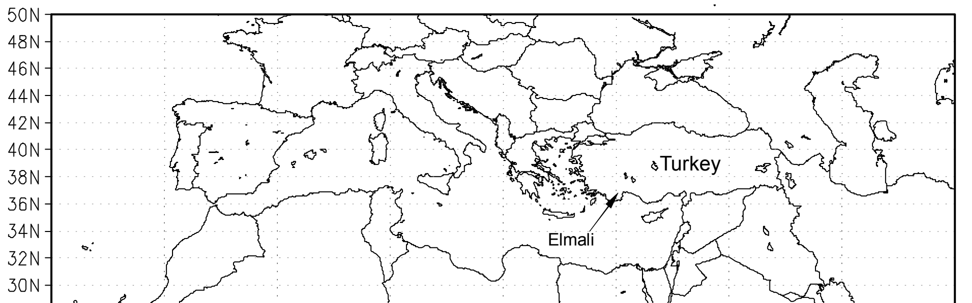

Figure 1: Map with location of the sample site near Elmali (36°36'N / 30°01'E), Antalya district, southwest Turkey at an elevation of 1300-2400m a.s.l.

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At least three cores per tree of 12 *Juniperus excelsa* living trees were taken. In addition, full cross sections were sampled from 14 stumps and logs (Touchan et al. 2007). This resulted in a sample pool of 54 cores and 14 stem disc samples which were fine-sanded and crossdated using standard dendrochronological techniques (Stokes and Smiley, 1996). From a sample pool of 68 trees of *Juniperus excelsa* M. Bieb., twelve trees 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 and Schleser 2004) and pyrolised to CO at 1350°C for mass spectrometer analysis (Delta V advantage, Thermo Fisher Scientific, Dreieich, Germany) of $^{18}O/^{16}O$ ratios, without any pooling applied to the individuals. Oxygen isotope ratios are expressed in the conventional δ–nomenclature. $\delta^{18}O$ values are given in per mil (‰) as deviations from the Vienna Standard Mean Ocean Water (VSMOW) (Mook 2001). The individual $\delta^{18}O$ series, without transformation or detrending, were finally averaged into one mean site chronology reaching back to the year 1025 AD. However, it was cut off at the year 1125 AD when sample size dropped below 5 individuals.

The $\delta^{18}O$ site chronology was then correlated with monthly, seasonal and annual climate data, i.e., precipitation and temperature from the meteorological station Elmali (data available for the time period 2000 to 1960), and the self-calibrating Palmer Drought Severity Index (scPDSI) from the CRU data set (data available for the time period 2002 to 1901) (van der Schrier et al. 2006), located near the study site, using Pearson's simple correlation coefficient. Furthermore, river runoff data from the Euphrates River (Station Keban from the Euphrates headwater, 38°48′N / 38°45′E) were also correlated with the $\delta^{18}O$ site chronology (Data kindly provided by The Global Runoff Data Centre, 56068 Koblenz, Germany). The dominant climatic forcing factor which mainly controls tree growth was calibrated against the $\delta^{18}O$ site chronology. Furthermore, the river runoff data from Keban primarily related to the $\delta^{18}O$ site chronology were also used in a simple regression model. River runoff can be reconstructed from tree rings if both tree growth and streamflow are responding to regional precipitation and evapotranspiration patterns (Meko and Graybill 1995). The records were split into two equally long periods. The first period was used for calibration and the second for the independent verification of the data. 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 and streamflow factors. The verified simple linear regression model was then used to reconstruct climate and streamflow. Spatial correlation analyses were conducted in the KNMI climate explorer (van Oldenborgh 1999).

Results and Discussion

The $\delta^{18}O$ series does not contain long-term trends but reveals more high-frequency variability and thus does not require any low-frequency detrending (Fig. 2). The rbar and eps of 0.35 and 0.85, respectively, imply a good quality of the mean $\delta^{18}O$ chronology and that it is suitable for further dendroclimatic research.

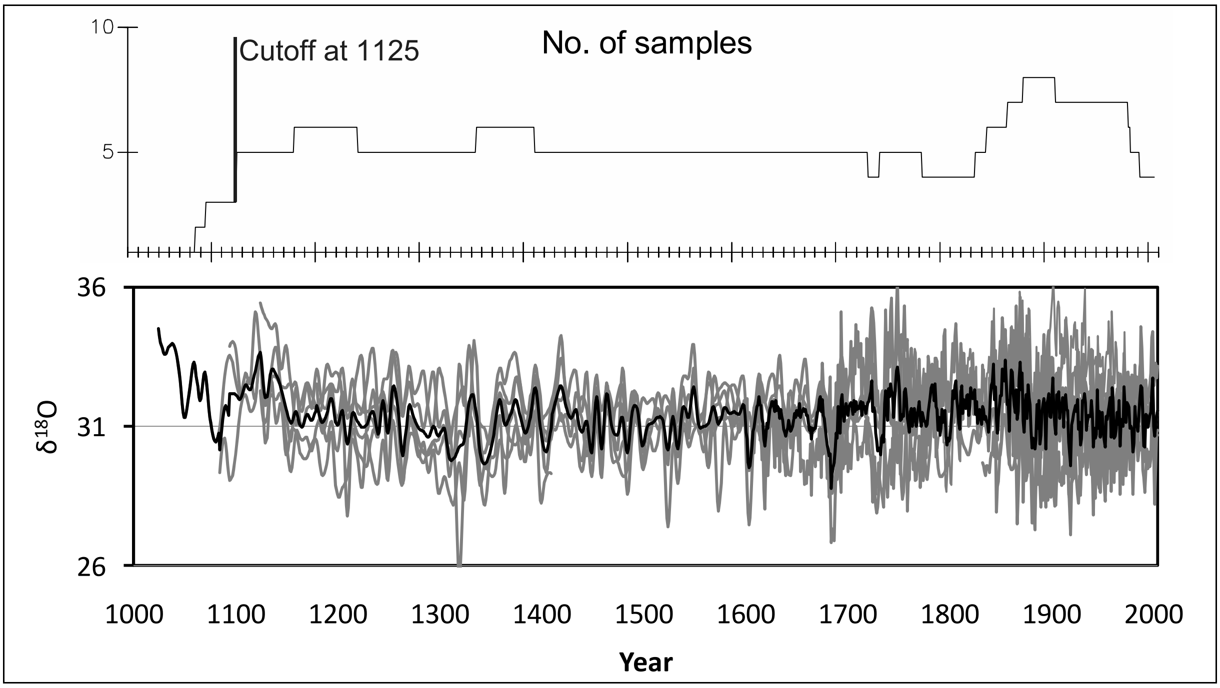

Figure 2: Plots of the $\delta^{18}O$ series (bottom) and sample depth through time (top). The black graph represents the mean site chronology. Series cut off in 1125AD when sample size drops below 5 (rbar=0.35; eps=0.85).

The climate response plots present correlations between the isotope chronology and climate data. The analysis includes monthly climate data of the current (J-D) and previous (j-d) year, annual and selected seasonal climate data. The analysis indicates highly significant positive correlations between $\delta^{18}O$ and May to July temperatures (r=0.53), negative correlations with May precipitation (r=-0.58) and with May to July scPDSI (r=-0.58) (Fig. 3). The correlation with scPDSI is highly significant for most months of the current year which leads to the assumptions of a distinct drought signal, recorded in the isotope record.

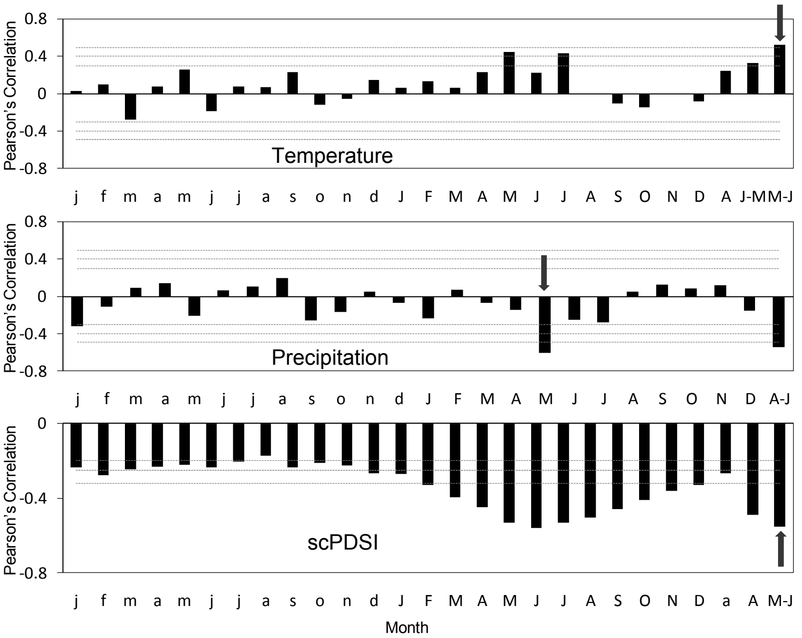

Figure 3: Climate response of the $\delta^{18}O$ series to monthly, annual and seasonal temperature (top), precipitation (middle) and scPDSI (bottom). Dashed lines represent levels of significance with p<0.5, p<0.1 and p<0.01. Arrows point to strongest correlations.

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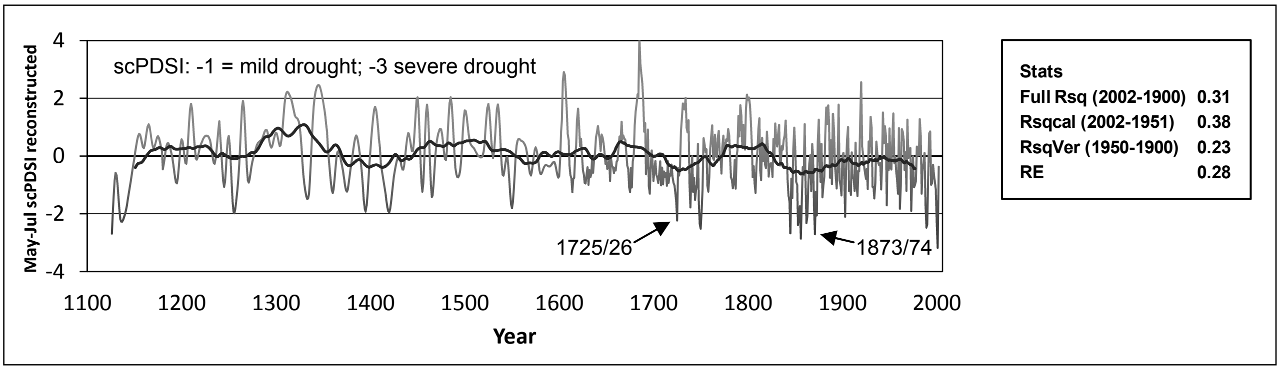
Overall, the strong drought signal in the δ^{18}O chronology confirms results by Touchan et al. (2007), suggesting highly significant correlations between a regional tree-ring chronology from southwest Anatolia and May to June precipitation. Tree-ring δ^{18}O mainly depends on the variability of two factors: i) the isotope values of the source water and ii) the ^{18}O enrichment of needle water due to evapotranspiration. In simple words, higher air temperatures lead to higher δ^{18}O values of rain drops and increasing amount of rainfall corresponds to lower δ^{18}O source values. After the rain water has been taken up by a tree from the soil it is partly being transpired and partly being used for photosynthesis. The magnitude of evapotranspiration, which is governed by the water vapour pressure deficit (vpd again is governed by the gradient between needleT and air T, air rH and stomatal conductance) between the inner needle and the ambient air, determines the extent of ^{18}O enrichment (high ^{18}O enrichment = high δ^{18}O) of needle water. Based on the highly significant relationship between δ^{18}O and May to July scPDSI a reconstruction of scPDSI was performed (Fig. 4).



Stats	
Full Rsq (2002-1900)	0.31
Rsqcal (2002-1951)	0.38
RsqVer (1950-1900)	0.23
RE	0.28

Figure 4: Reconstruction of summer scPDSI based on δ^{18}O with low frequency variation highlighted by 51-year moving average; robust reconstruction indicated by significant statistics; arrows indicate two historically documented drought periods (1725/26 and 1873/74) associated with catastrophic cultural changes

The statistics indicate a significant regression model and a stable reconstruction (Fig. 4). The reduction of error (RE) (Fritts 1976) which can range from -∞ to 1 is greater than 0.28, signifying that the model has good predictive skill. The low frequency oscillation is highlighted by a 51-year moving average. According to the reconstruction it was drier between the late 14th and early 15th century, in the early to mid 18th and in the second half of the 19th century. A more recent trend towards drier conditions since the 1960s is also shown. This corresponds well with historical archives, which suggests that a number of significant climate events are associated with catastrophic historical and cultural changes. For instance, major droughts and famine are reported around Anatolia and Syria in 1725–1726 (Panzac 1985). Kuniholm (1990) described a catastrophic drought in Turkey from 1873 to 1874. According to Naumann (1893), this drought in central Turkey in 1874 was of such devastating proportions that hunger and sickness during the winters of 1873–1874 killed more than 100 000 people. Moreover, wheat exports were banned due to drought-related shortages (Akkemik *et al.* 2007). Our reconstruction also reveals persistent drought events during the last three centuries confirming the droughts in the historical documents (Fig. 4).

The late 20th to early 21st century drought conditions have raised questions about whether these dry conditions are within the range of natural variability (Akkemik et al. 2007). In order to shed more light on the hydrology in Turkey, in a second part of the examination of the drought conditions in Turkey, a river streamflow reconstruction was conducted, incorporating a second environmental element, besides the drought index reconstruction. In the past, streamflow records for Turkey have proven useful in evaluating, for example, the impact of the North Atlantic Oscillation on Tigris-Euphrates streamflow (Cullen and deMenocal 2000), and mid-latitude streamflow responses to the extreme phases of El Nino-Southern Oscillation (Kahya and Karabork 2001).

However, most river flow data from the Antalya region are relatively short, i.e., usually less than 20 years, or of poor quality because of missing data. Considering a wider region around the site Elmali, one of the longest records available is from the Euphrates River (Keban station, 37years).

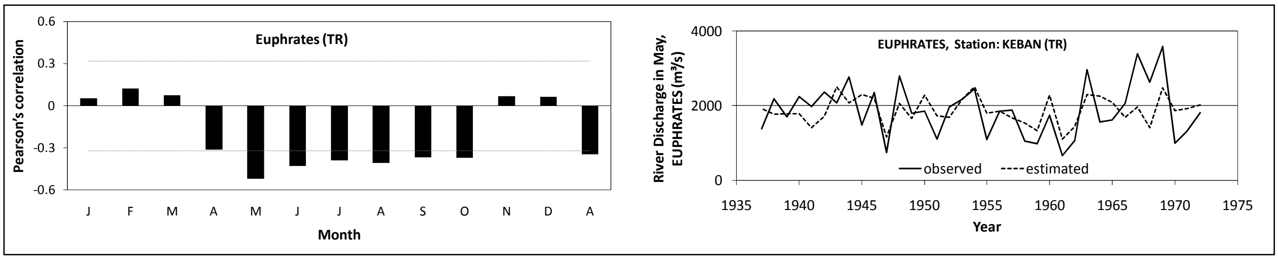


Figure 5: Response of the $\delta^{18}O$ series to monthly and annual Euphrates River runoff. Dashed lines represent levels of significance with $p<0.5$ (left); comparison of observed and estimated Euphrates River runoff (right)

The river flow data from the Keban station were correlated with the tree-ring data. The response plot presents correlations between the $\delta^{18}O$ chronology and the monthly and annual Euphrates River runoff data. The analysis indicates significant negative correlations for May to October runoff data, but the strongest correlation is suggested for May (r=-0.52) (Fig. 5, left panel). This strong correlation in May indicates two things. It seems that a large part of the tree-ring width is grown during May and thus plays an important role during the isotope analysis. In addition, high amounts of precipitation result in low $\delta^{18}O_{TR}$ because of low source $\delta^{18}O$ and low ^{18}O enrichment due to relatively low evapotranspiration rates. And these relationships seem to hold true in a similar way for both regions, that is, the Antalya region and the catchment area of the Euphrates River.

Thus, a regression model with May runoff and $\delta^{18}O$ data was computed. The visual comparison of the observed and the estimated May runoff demonstrates the ability of the model to reconstruct river runoff (Fig. 5, right panel). This skill is also expressed by the reconstruction statistics (Fig. 6, right panel). The reduction of error of 0.14 verifies that the reconstruction accurately reproduces any changes between the calibration and validation period means (Touchan *et al.* 2010).

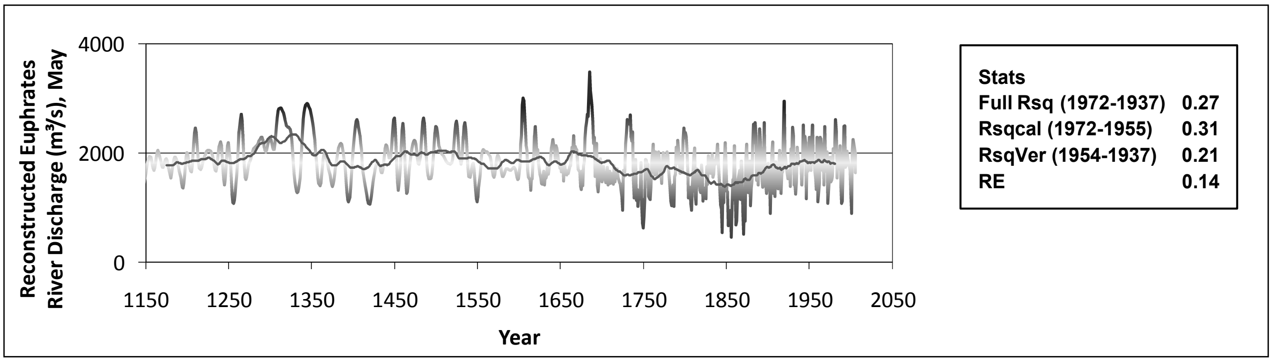


Figure 6: Reconstruction of Euphrates River runoff (May) based on $\delta^{18}O$ with low frequency variation highlighted by 51-year moving average; robust reconstruction indicated by significant statistics

The reconstruction based on this regression is presented in Fig. 6 (left panel), indicating low flow conditions for longer periods during the late 14th and early 15th century, second half of the 16th century and between the 18th and 19th century. Between 1850 and 1950 an increasing trend is suggested but since the 1950s the May runoff is slightly declining.

It seems understandable that most of the trends in the scPDSI and river runoff reconstructions are the same but does it really make sense to reconstruct Euphrates River flow by means of $\delta^{18}O$ tree-ring data derived from trees growing approximately 1000 km to the west of the Euphrates?

The fact that the climate and river flow response plots indicate the most significant correlation patterns for the same time of the year, namely May to July, indicates by itself already that such a reconstruction seems feasible. Such a synchronism of the correlation patterns implies an interrelation between precipitation, scPDSI, riverflow and $\delta^{18}O$ tree-ring data. Furthermore, Keban is the most suitable station because it is situated at the confluence of the two sources Murat and Karasu and therefore, the discharge data come from the uppermost and the least disturbed part of the full Euphrates. The data we used for the reconstruction are from the period 1937 to 1972 which was before the Keban dam was completed in 1974, and the dam´s reservoir began to fill only that year (Kalpakian 2004). Thus, the data come from the upper undisturbed Euphrates from a period when the human impact on the river system was relatively mild, which, in comparison to other reconstructions, is an advantage because no *a priori* adjustments to the Euphrates river flow data due to the human impact need to be done (*cf.* Woodhouse *et al*. 2006; Meko *et al.* 2007).

Although the reconstruction accounts only for one month, the Euphrates River discharge which takes place in May represents 25% of the annual total and together with the April discharge is the most important month (Fig. 7).

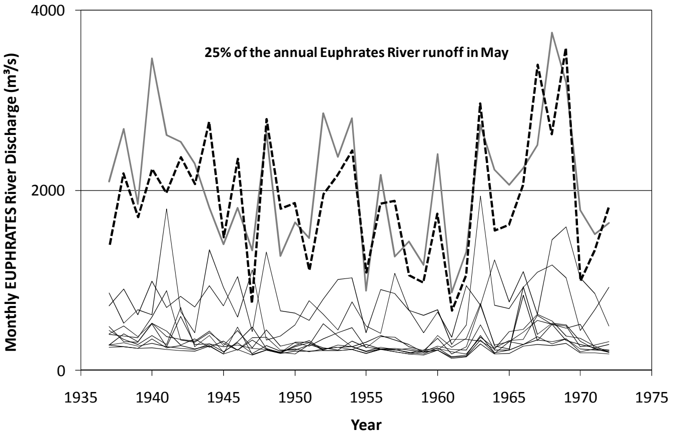


Figure 7: Monthly Euphrates River discharge (m^3/s); note that 25% of the annual discharge takes place in May (dashed line) and also in April (grey line), together representing 50% of the annual total (Data kindly provided by The Global Runoff Data Centre, 56068 Koblenz, Germany).

Since the reconstruction of the Euphrates discharge is based on $\delta^{18}O$ tree-ring data from 1000 km to the west it is interesting to examine the spatial correlations between precipitation, scPDSI and the discharge data. The first step is to analyse the spatial correlation between the local May precipitation record from Elmali and the CRU grid precipitation data set for the same month. In a second analysis, the Euphrates discharge data in May derived from the Global Runoff Data Centre were spatially correlated with the CRU grid scPDSI data also for May. In the first analysis the overview map (Fig. 8, left panel) indicates a locally confined correlation with a tendency to the southeast. When zooming in a highly significant correlation of the Elmali station data with large parts of the Euphrates catchment area is revealed (Fig. 8, right panel).

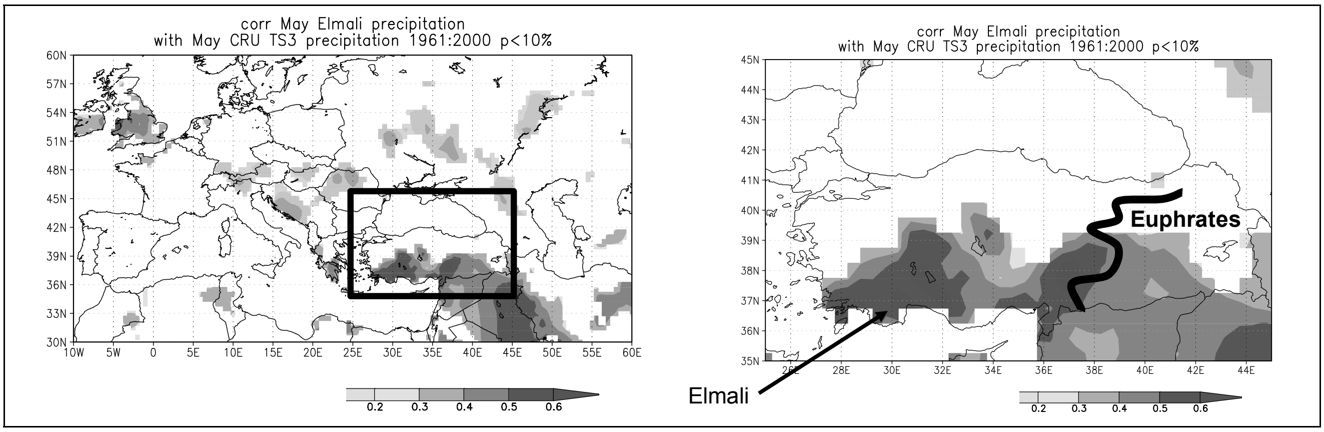


Figure 8: Spatial field correlations (van Oldenborgh 1999) between May precipitation derived from the meteorological station Elmali (36°36'N / 30°01'E) and the gridded May CRU precipitation; rectangle indicates zoomed area for right map; arrow indicates location of the study site; course of the Euphrates River is also indicated

The second analysis, Euphrates runoff station data with May scPDSI CRU grid data, suggests an even stronger local confinement of the correlation mainly to Turkey (Fig. 9, left panel). The Euphrates runoff station data correlate well with most southern parts of Turkey including the Elmali site (Fig. 9, right panel).

Both comparisons indicate a good coherence between the climate parameters of the Elmali region and the Euphrates catchment zone, and therefore it seems feasible to reconstruct runoff from the east of Turkey with δ^{18}O tree-ring data from the west.

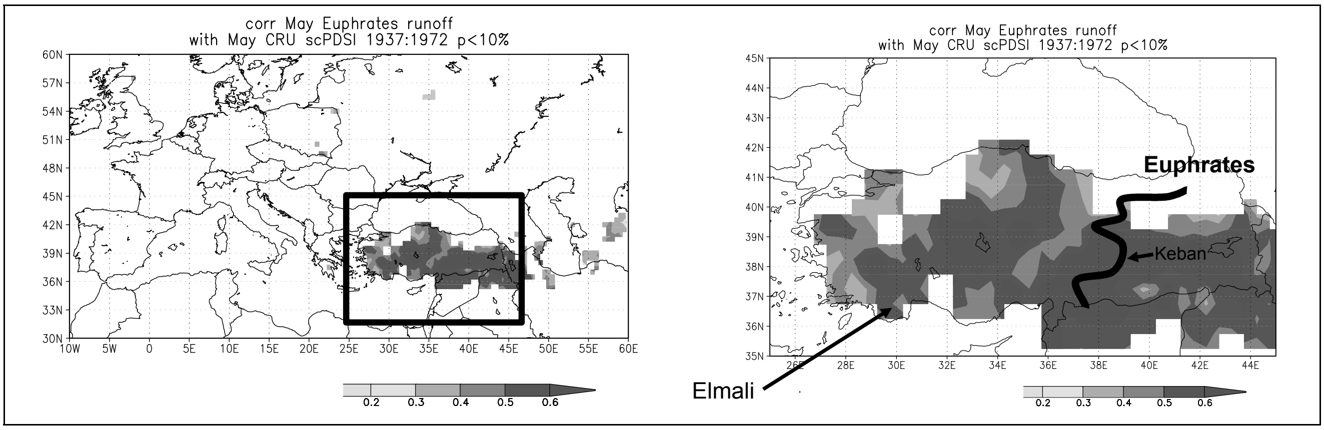


Figure 9: Spatial field correlations (van Oldenborgh 1999) between the Euphrates River runoff data from the station Keban (38°48'N / 38°45'E) with the gridded May CRU scPDSI; rectangle indicates zoomed area for right map; arrows indicate locations of the study site near Elmali and Keban river runoff gauging station; course of the Euphrates River is also indicated

In conclusion, it was possible for the first time to use δ^{18}O tree ring chronologies from Turkey to reconstruct long-term drought variations and Euphrates River runoff. The Euphrates has always been one of the most important rivers in the region. It seems likely that in much of Turkey, δ^{18}O tree-ring data can provide a proxy for gauge records because the same climatic factors, primarily precipitation and scPDSI, control both the growth of moisture-limited trees and processes related to streamflow.

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The manifestation of drought events in tree rings of beech and oak in northern Bavaria (Germany)

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Introduction

The frequency and intensity of climatic extreme events is expected to increase in the near future in central Europe as a consequence of climate change (Schär et al. 2004). For northern Bavaria, an increase of summer temperatures of up to 2.4°C is expected, while summer precipitations are predicted to decrease (Rennenberg et al. 2004). Some climatic events manifest themselves by characteristic features such as frost rings, light rings, false rings or reaction wood. Droughts or severe storms are expressed by abrupt growth reductions which might alter growth for a number of years (Schweingruber 2001). Drought events might alter the intrinsic water use efficiency of trees and document themselves in variations of stable isotopes in wood cellulose (Bonn 2000, Skomarova et al. 2006). We present first results of a project ("FORKAST") studying the effects of extreme drought events on trees of edaphically dry sites in northern Bavaria (Germany) during the last century. Special emphasis is laid on the resilience time needed by different tree species for recovering from extreme drought. We investigate a spatial network of chronologies of common beech (*Fagus sylvatica* L.) and sessile oak (*Quercus petraea* (Mattuschka) Liebl.) by applying a multi-parameter approach including quantitative analyses of intra-annual variations of wood anatomy, wood density and carbon isotopes. The final goal of this study is to assess the adaptability of these tree species if frequency and intensity of drought events will increase in the near future. This will lay a dendroecological basis for forest management actions that may have to be taken in order to modify the forest structure on drought-prone sites as an adaptation to future climate change.

Material and Methods

Study sites and climate data

The study sites selected (Fig.1) show intermediate or shallow soil depths on clay, sand or limestone and cover an annual precipitation range from ~600 mm (Markt Zellingen) up to ~900 mm/a (Geisfeld Ottobrunnen) and an annual mean temperature range from 7.6°C up to 9.1°C. At each site, fifteen dominant and five subdominant trees of each species were sampled with two cores per tree obtained at breast height As predictor variables for growth/climate analyses, monthly temperature and precipitation series from the nearest climate stations (obtained from Germany's National Meteorological Service (DWD)) and the self-calibrating Palmer Drought Severity Index (scPDSI; a measure of regional soil moisture availability; van der Schrier et al. 2006) are used. The most severe drought events are defined as years in which the annual precipitation sum departs more than one standard deviation from the mean annual precipitation sum .

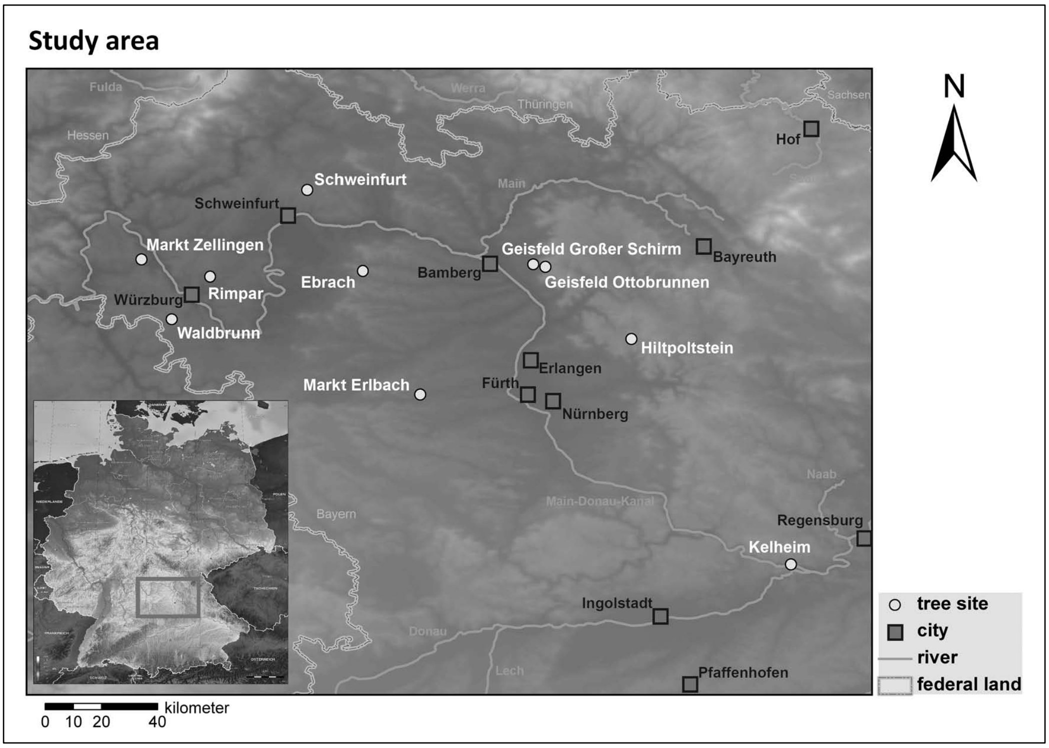

Figure 1: Network of study sites established in northern Bavaria for the FORKAST-project.

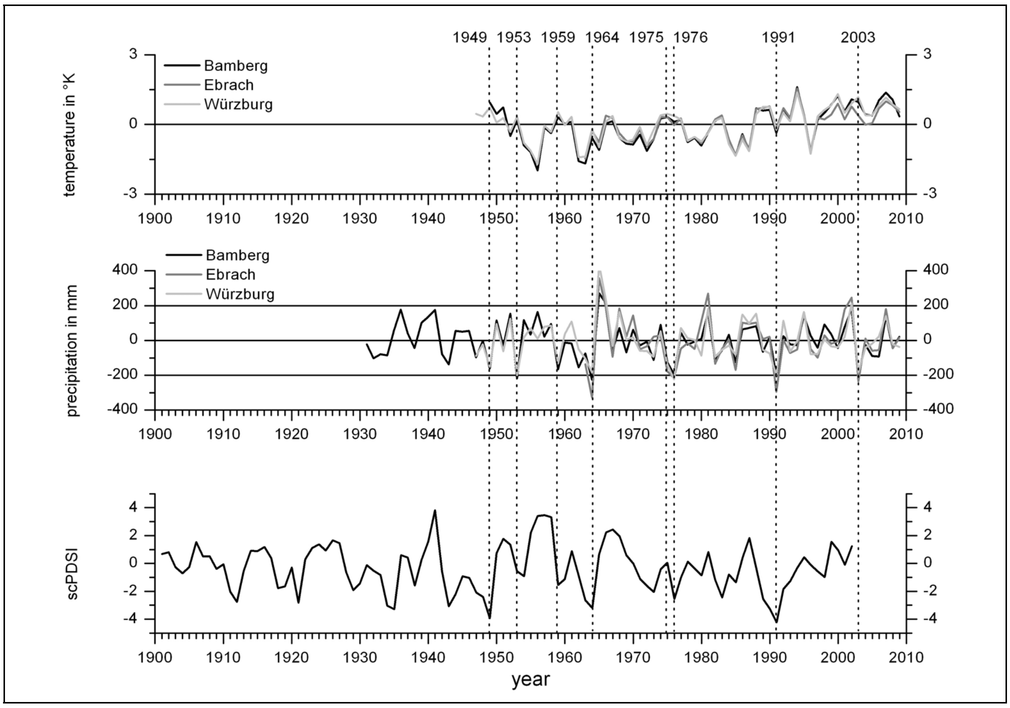

Figure 2: Deviation of annual temperature and precipitation of the climate stations Würzburg, Ebrach and Bamberg from mean, scPDSI and most severe drought events (dashed vertical lines).

Tree-ring data

The samples were prepared according to standard procedures (Cook & Kairiukstis 1990). Individual tree-ring width measurements were visually cross-dated (Fritts 1976) prior to tree ring standardization using the program ARSTAN (Cook 1985). A cubic smoothing spline with a 50% frequency cut-off at 67% of the individual tree ring series length was applied to remove biologically induced age-trends and to retain high-frequency variations (Cook & Peters 1981). Standard chronologies were computed using a bi-weight mean removing the effects of endogenous stand disturbances and enhancing the common signal contained in the data (Cook & Holmes 2008).

Statistical analysis

Pointer years after Cropper (1979) were calculated using a threshold of +/- 0.75 and regional pointer years identified when more than 50% of the study sites showed the same reaction. Pearson´s correlation coefficients between tree-ring chronologies and climatic data were calculated using DENDROCLIM2002 (Biondi & Waikul 2004). Superposed epoch analysis testing for mean growth response during the most severe drought events was calculated and the significance levels (p<0,05) were estimated from confidence intervals derived from bootstrap sampling with 1000 samples using dplR-package in R (Bunn 2008).

Results

The tree-ring chronologies of each species show a clear synchronicity among the study sites, but significant differences between the two species and only few common negative regional pointer years (Fig. 3). The negative regional pointer years and other strong declines of *F. sylvatica* coincide with (most) severe drought events (Fig. 3), their consecutive year (1953, 1960, 1964, 1971, 1976, 1986, 1992, and 2003) and/or with regional mast years (1948, 1960, 1992, and 2009, Dittmar & Elling 1999). For *Q. petraea*, however, the pattern is less clear: only few negative regional pointer years of *Q. petraea* coincide with (most) severe drought events (1964, 1976, and 2005). Some pointer years occur during wetter and colder conditions (1956, 1968, and 1996), whereas others have probably to be attributed to mast years or insect calamities for which no data were available.

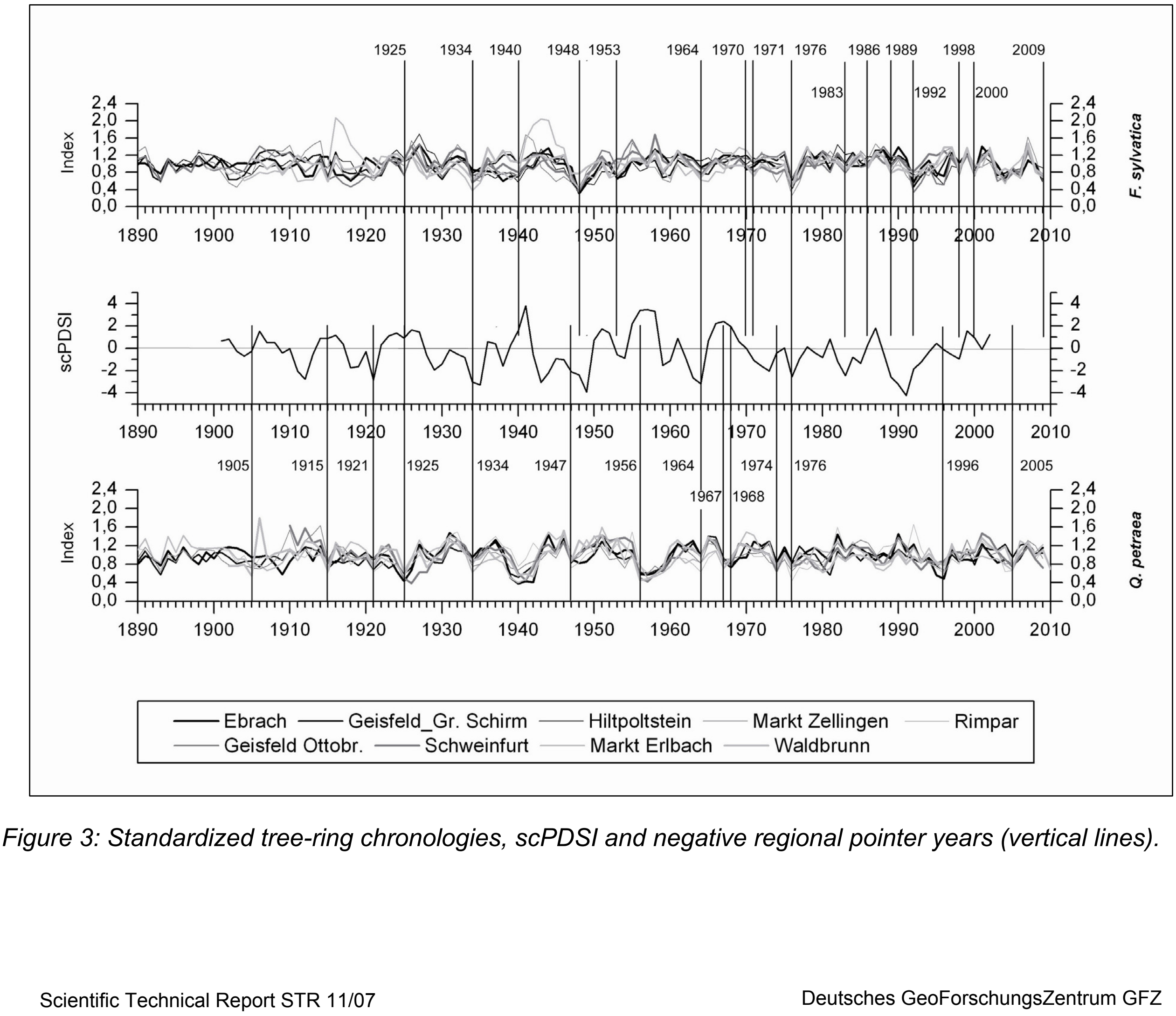

Figure 3: Standardized tree-ring chronologies, scPDSI and negative regional pointer years (vertical lines).

These observations are confirmed by the results of the superposed epoch analysis. For *F. sylvatica* (Fig. 4A), the majority of sites show a highly significant growth decrease in the most severe drought event years (year 0) and/or in the consecutive year (year 1). Only at site Hiltpoltstein, trees do not show such a pronounced growth decline. This might be attributed to a major die-off phase after the drought year 2003, so that the remaining trees sampled might be better adapted to drought events. The recovery reaction on all sites is accomplished two years after the extreme event (year 2). In contrast, *Q. petraea* is much less affected by the most severe drought events as only few sites show a weak, statistically non-significant decrease in tree-ring width in the event year or its consecutive year (Fig. 4B).

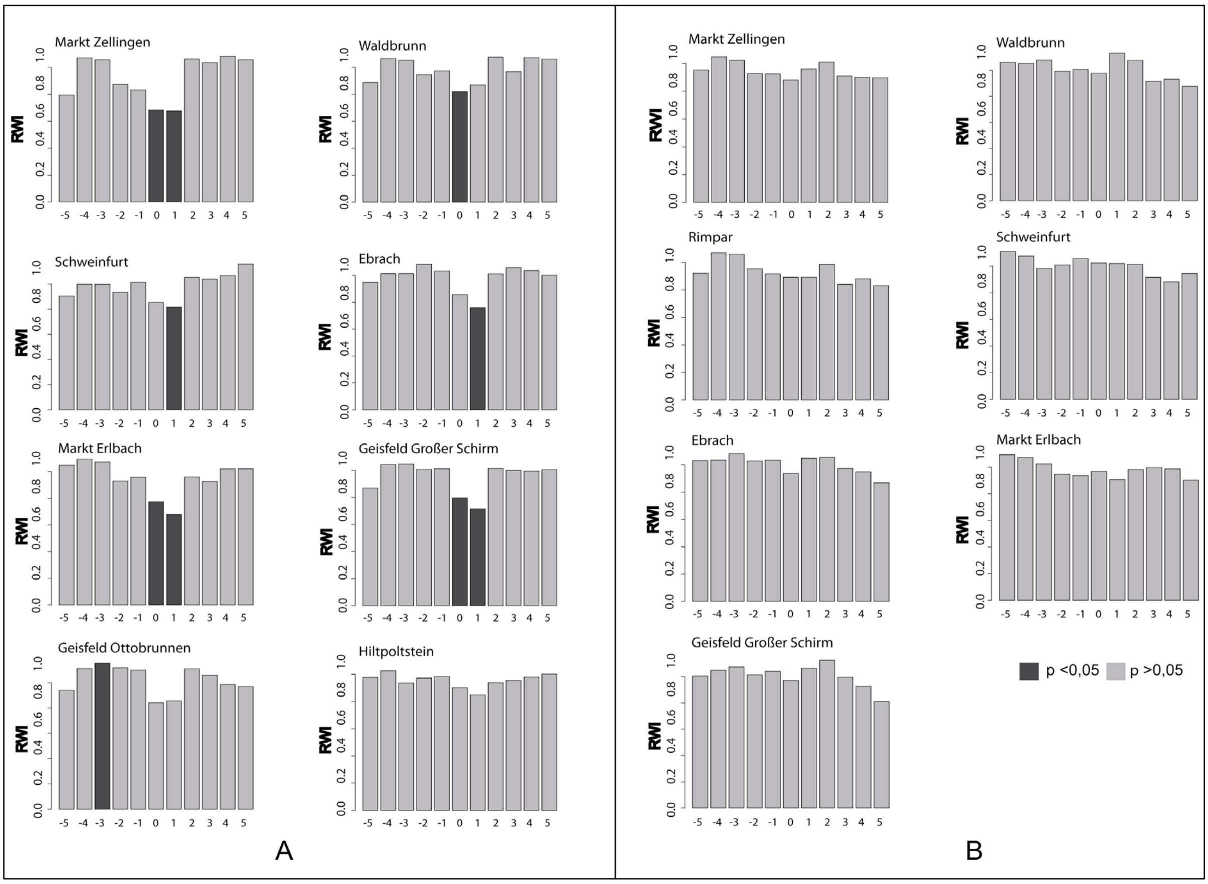

Figure 4: Superposed epoch analysis of the eight most severe drought years for F. sylvatica (A) and Q. petraea (B).

The Pearson´s correlations between tree-ring width, temperature, precipitation and the scPDSI (Fig. 5) reveal significant differences between *F. sylvatica* and *Q. petraea* which are in line with the results discussed above. *Fagus sylvatica* shows a strong positive correlation with the scPDSI (whose high auto-correlation can be seen in the diagram) especially during late summer and autumn of the previous year and during the summer months of the actual year. This means that high available soil moisture favors growth, especially when the soil water reserves are replenished in winter to provide water reserves during the hottest months. The negative correlation between tree-ring width and temperature and the positive correlation with precipitation during the summer months of the previous and actual year confirm the sensitivity of this species to summer drought.

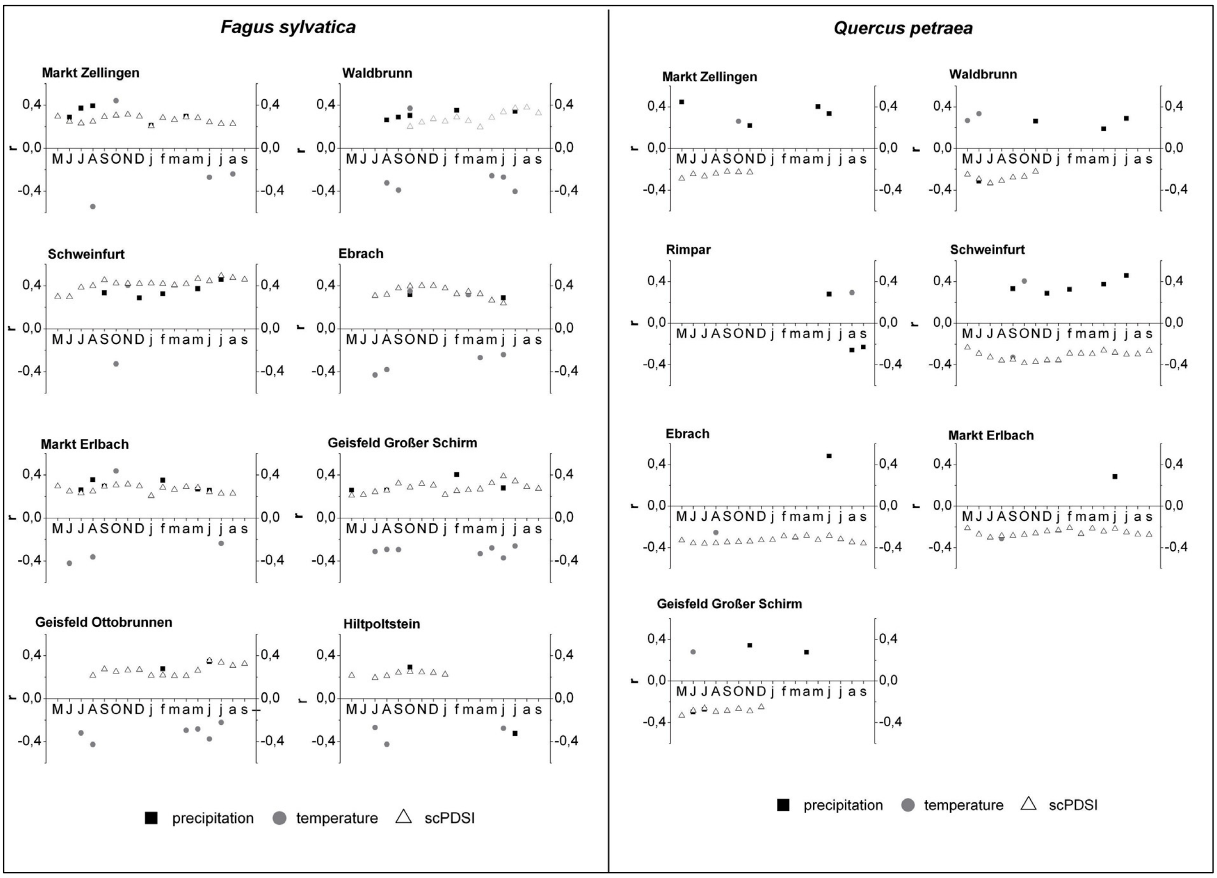

Fig. 5: Pearson´s correlation coefficient between annual precipitation, mean temperature and scPDSI and tree-ring width of F. sylvatica and Q. petraea.

Conclusions

Our results confirm those of previous studies revealing the sensitivity of *F. sylvatica* to drought and the importance of the previous year conditions for physiological processes (Friedrichs et al. 2009). Moreover, they clearly show that *Q. petraea* is much less affected by extreme drought events and seems to be better adapted to actual and possibly future prevailing climatic conditions on edaphically dry sites. Under present conditions, the recovery reaction of *F. sylvatica* still seems to be fast enough to recover between consecutive drought events. However, observations on severe damages of beech after drought events have been made by foresters, which points to an increasing risk of drought damage. These results will have to be reconfirmed and refined by successive analyses of wood anatomy, δ^{13}C isotope variations and species-specific intrinsic water use efficiency.

Acknowledgements

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Influence of volcanic eruptions on tree growth in NE-Germany during the last Millennium

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Introduction

The availability of light energy, water and specific temperature are the essential parameters for plants to photosynthesize. Thus a change in these meteorological conditions results in an altered plant net primary production and eventually in a modified tree growth.

One main scientific topic worldwide is climate change and the reasons for it. To discuss the change in climate is not the task of this work rather to focus on one potential control parameter steering weather conditions and the impact on tree growth such as the consequences of volcanic eruptions. Large eruptions of volcanoes have strong impacts on the global climate (Battipaglia et al. 2007, Latif 2009, Schweingruber 1996, Gao et al. 2008), lowering the global temperature (Press & Siever 1995, Robertson et al. 2001) and increasing the diffuse light fraction for one to several years after the eruptions (Krakauer et al. 2003, Gu et al. 2003). It has been argued that due to scattering by volcanic sulfur aerosol the more diffuse light fraction can be used more efficiently by forests. However, other observations suggest a growth decrease because of the cooler conditions following large eruptions. Trees growing to the north of the temperate zone are mainly temperature-limited (*e.g.*, Esper et al. 2002) and therefore a reduction in ring width after large volcanic eruptions seems inevitable. Since tree growth in the temperate zone is less limited by temperature than by other climate parameters such as precipitation, we hypothesize that tree growth may not suffer from lower temperatures so much but profit from increased diffuse light and reduced water stress.

Our goal is to compare different tree species at various sites in eastern Germany to test whether tree growth suffered or profited from the globally changed conditions after large eruptions during the last millennium.

Material and Methods

Study area

The study material was collected at three different locations in eastern Germany (Fig. 1).

In general, the tree-ring data pool is based on heterogenous archaeological material from the three sites. The material of Greifswald and Eberswalde was collected in the direct surroundings of the two cities (part B in Fig. 2 (1-6)). In contrast, the data pool from Saxony comprises numerous site chronologies and originates from the foothills of the Erzgebirge, a mid range mountain chain in the South of Saxony. In Saxony, *Quercus robur* L. (part B in Fig. 2 (1)) was collected on fertile soils in the area of Dresden/Meißen/Torgau (Fig. 1) and *Pinus sylvestris* L. on rather sandy soils (part B in Fig. 2 (1)) in the surroundings of Dresden/Kamenz/Görlitz (Fig. 1).

Temperature and precipitation data back to 1901 were extracted from the webpages of the Climate Research Unit (http://www.cru.uea.ac.uk) to characterise the climatic conditions of the regions of interest.

In general, the study sites are all located within a temperate warm and humid climate, usually experiencing warm summer temperatures (Kottek et al. 2006).

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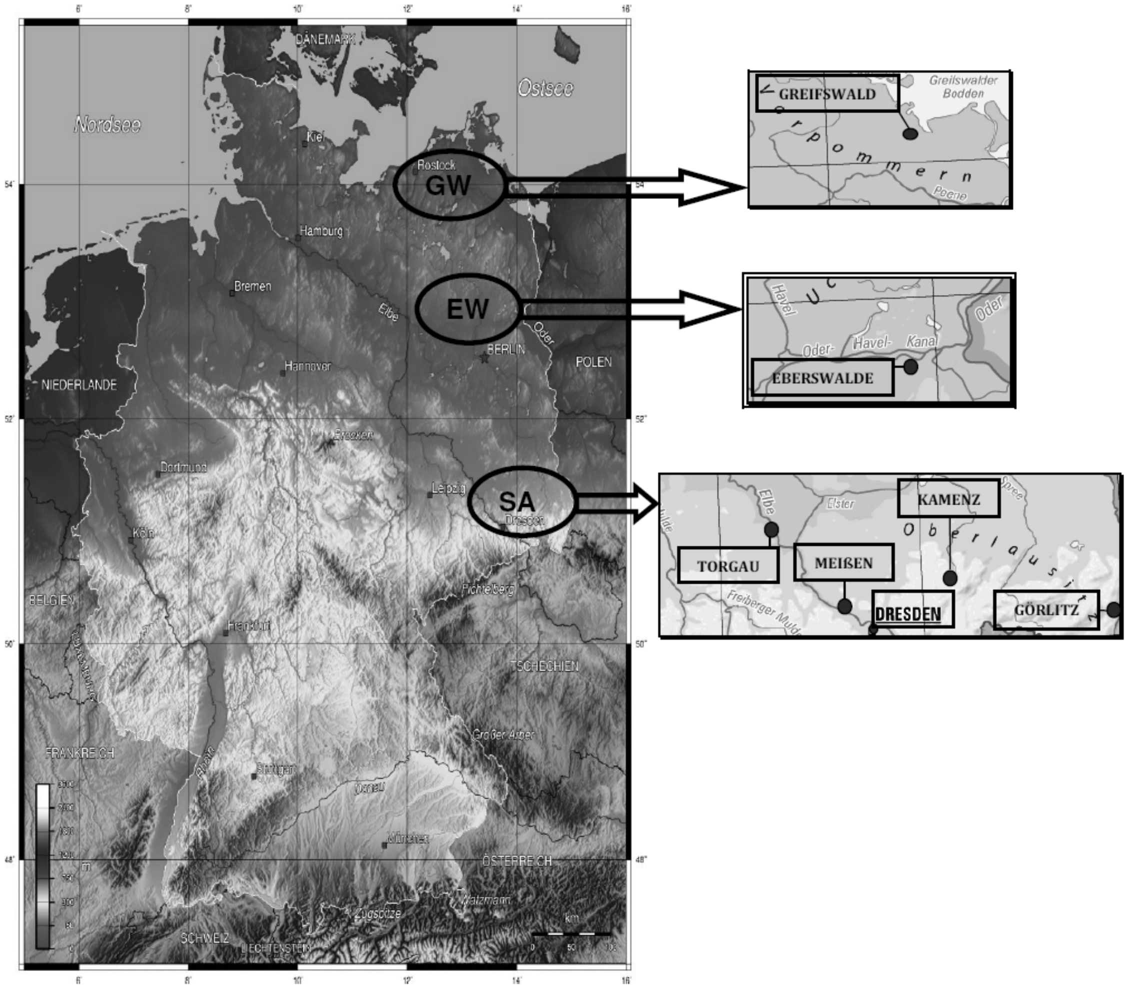


Figure 1: Location of the study sites (GW: Location Greifswald, EW: Location Eberswalde, SA: Location Saxony)

However, the three locations differ notably in regard to precipitation rates and temperatures. The site Saxony is more continental with drier summers than Greifswald and Eberswalde. The lower annual precipitation sum (precip/sum = 547mm) and the higher mean summer temperature (JJA = 18.1°C) in Saxony are characteristic for a more continental climate in comparison to Greifswald (precip/sum = 562mm, JJA = 16.74°C) and Eberswalde (precip/sum = 560mm, JJA = 17.67°C). Hence, in Saxony water is likely to be a more limiting factor to tree growth than in Greifswald and Eberswalde and can lead to drought stress for the vegetation. Eberswalde is also characterized by a continental influence but with a higher precipitation rate, therefore trees are likely to be less drought-stressed than in Saxony. Greifswald is the most maritime location characterized by balanced temperatures, relatively high amounts of precipitation and comparatively mild winters.

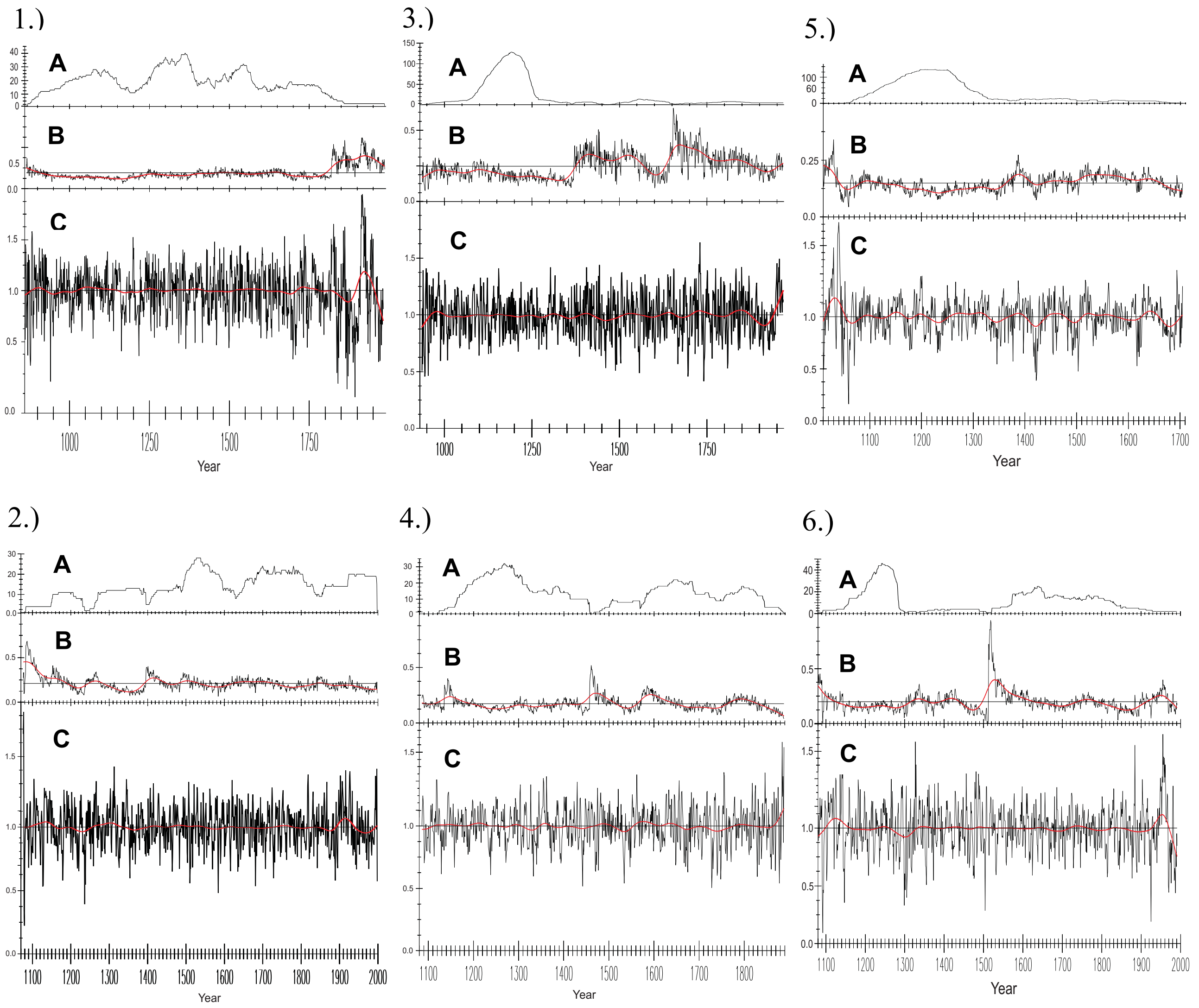


*Figure 2: (1-6): Overview of all sites and tree species with **A**: Number of samples; **B**: Raw ring width chronology; **C**: Standard Chronology ; a: Quercus from Saxony (QS) ; b: Pinus from Saxony (PS) ; c: Quercus from Greifswald (QG) ; d: Pinus from Greifswald (PG) ; e: Quercus from Eberswalde (QE) ; f: Pinus from Eberswalde (PE).*

We used a database of long tree-ring chronologies of two different tree species (*Quercus robur* L. and *Pinus sylvestris* L.) from three sites in eastern Germany (Fig. 2), covering more or less the last millennium (Tab. 1).

Table 1: Temporal intervals of the series of the two tree species from the three sites

	Sites		
Tree Species	Greifswald	Eberswalde	Saxony
Pinus sylvestris	1086-1888	1079-1991	1076-1998
Quercus robur	909-1968	1010-1705	782-1986

Besides, we used a time series of annual mean Northern Hemisphere 550-nm optical depth since 1000 CE (Crowley 2000) (http://www.ngdc.noaa.gov/paleo/pubs/crowley.html) to identify eruption years. This time series was derived primarily from high-resolution ice core sulfate measurements calibrated against atmospheric observations after modern eruptions. Eruption years were defined as years with a peak in volcanic aerosol forcing by using the volcanic explosivity index (VEI) (Newhall & Self 1982) The VEI uses geological evidence as a proxy for the measure of the power of the eruption and can range from 0 to 8 (Simkin & Siebert 1994). In this study we used strong volcanic eruptions with VEI of 4 or higher. Subsequently, we focused on large volcanic eruptions like Tambora 1815, Krakatau 1883 and Pinatubo 1991.

Furthermore, we collected additional volcanic eruption year dates from various sources (Gervais et al. 2001, Gao et al. 2008, Briffa et al. 1998a, LaMarche Jr. et al. 1984, http://www.volcano.si.edu/). For the Southern Hemisphere sites, we used Southern Hemisphere volcanic-aerosol optical depths from the time series of Robertson et al. (2001). (http://www.ngdc.noaa.gov/paleo/pubs/robertson2001/robertson2001.html). This time series extends back to 1500 and was also primarily derived from ice core records. Overall, we obtained 49 eruption years (Fig. 3) for the period 1000-2000.

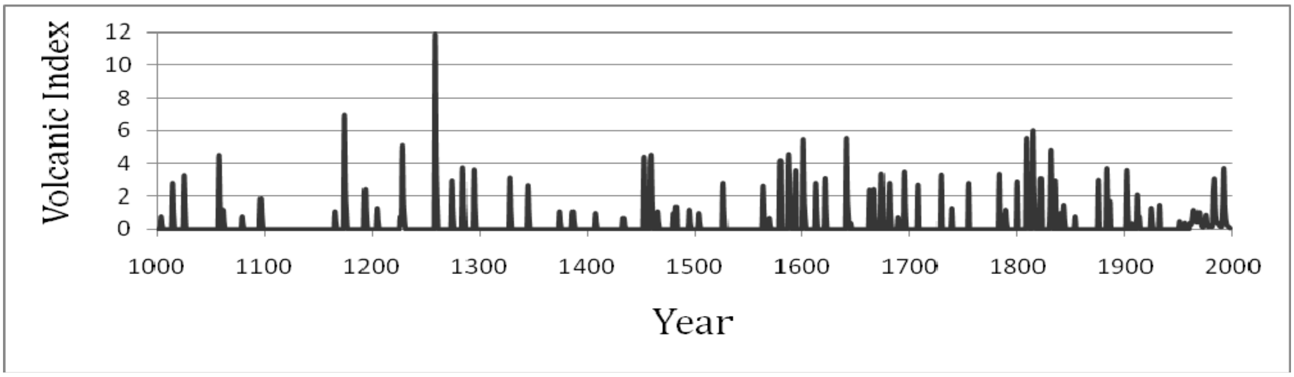


Figure 3: Overview of the 49 major volcanic eruptions derived from natural archives such as ice cores selected for comparison with tree rings for the period 1000-2000.

The tree-ring series were first checked for their crossdating qualities using TSAPWin (Rinn 2003) and COFECHA-software (Holmes 1983). In a first step, only highly correlating ring-width chronologies were selected for further detrending in ARSTAN (Cook 1985). The remaining ring-width series were standardized by fitting the Hugershoff growth curve model to the individual tree-ring series in order to remove biological growth trends as well as other low-frequency variations and to preserve all high-frequency signals (part C in Fig. 2 (1-6)). The detrended tree-ring series were examined individually for their reactions to large volcanic eruptions. The analysis was conducted by comparing boxplots (Fig. 5) focusing on growth trends of tree-ring series two years before and after the 45 strongest volcanic outbursts during the last 1000 years to test whether positive, negative or neutral tendencies within tree growth exist (Tab. 2). After the normal distribution of the data was determined the growth trends before and after each volcanic eruption were exposed to a Student's t-test (with $p = 0.05$ (two-tailed) as the significance level) to examine if significant differences in tree growth after volcanic eruptions could be detected.

Additionally, we analyzed the overall response of the standardized site chronologies of the two tree species at the three sites five years before and after the volcanic eruption (Fig. 4).

Furthermore a pointer year analysis was conducted to detect the influence of volcanic eruptions on tree growth. This method investigates the reaction of trees to unusually favorable or unfavorable conditions via the formation of exceptionally wide or narrow tree rings (Schweingruber et al. 1990). The pointer years were analyzed on the basis of the Cropper-method (Cropper 1979). That means that for the individual tree-ring width series indices are calculated through the ratio of each standard mean curve with a 13-year low-pass filter followed by a z-transformation of the index values in a 5-year moving window.

The pointer year analysis was repeated with the computer program WEISER developed by Gonzales (2001), which also analyzes the individual data series for pointer years.

Results and Discussion

Despite two delayed negative growth reactions (Quercus from Greifswald, QG (Fig. 4-c) and Pinus from Eberswalde, PE (Fig. 4-f)) an immediate negative signal of all tree species was clearly visible when analyzing the overall response of the standardized site chronologies five years before and after the volcanic eruptions (Fig. 4).

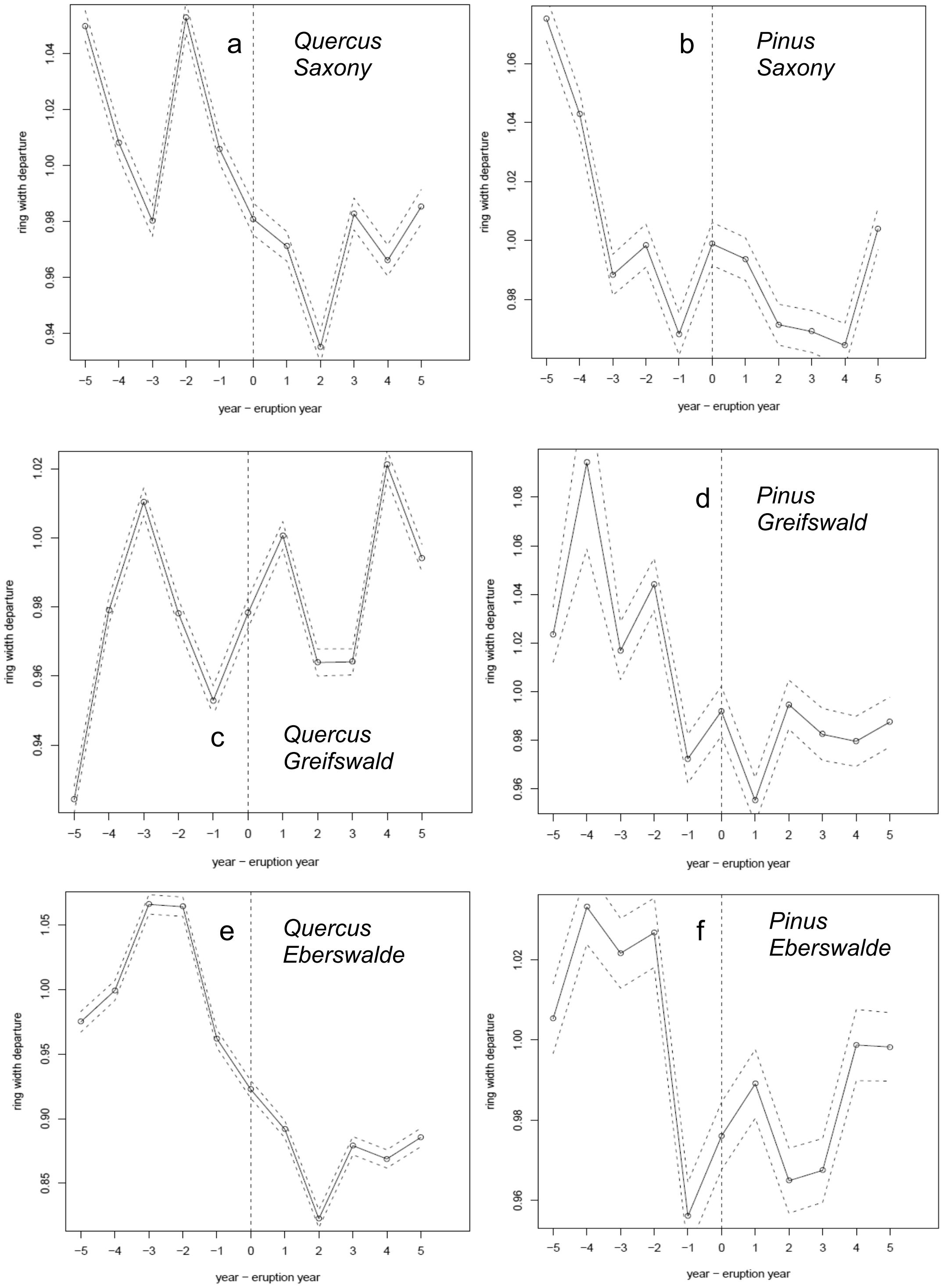


Figure 4 (a-f): Mean ring width departures before and after eruption years (0), separated by site and tree species. Tree–ring width departures are expressed in absolute values. Dashed blue lines show confidence intervals based on the variations across eruption years.

Most negative growth trends after the eruption lasted for two years except for *Pinus* from Greifswald (PG) and *Pinus* from Saxony (PS). At PG the negative trend lasted for one year (Fig. 4-d) and at PS it was even stronger and lasted for 4 years (Fig. 4-b). Generally, the growth rate decline within the five year interval after the eruption, compared to the five years before the eruption, except for QG (Fig. 4-c) and PE (Fig. 4-f) which increase at the fourth year after the eruption. Comparing all ring-width departures in Fig. 4, *Quercus* from Eberswalde (QE) (Fig. 4-e) shows the largest reduction.

The analysis of the individual reactions of the tree-ring series to large volcanic eruptions two years before and after the 49 strongest volcanic outbursts during the last 1000 years (e.g. Fig. 5) displays three different growth trends (negative, positive and neutral) as seen in table 2.

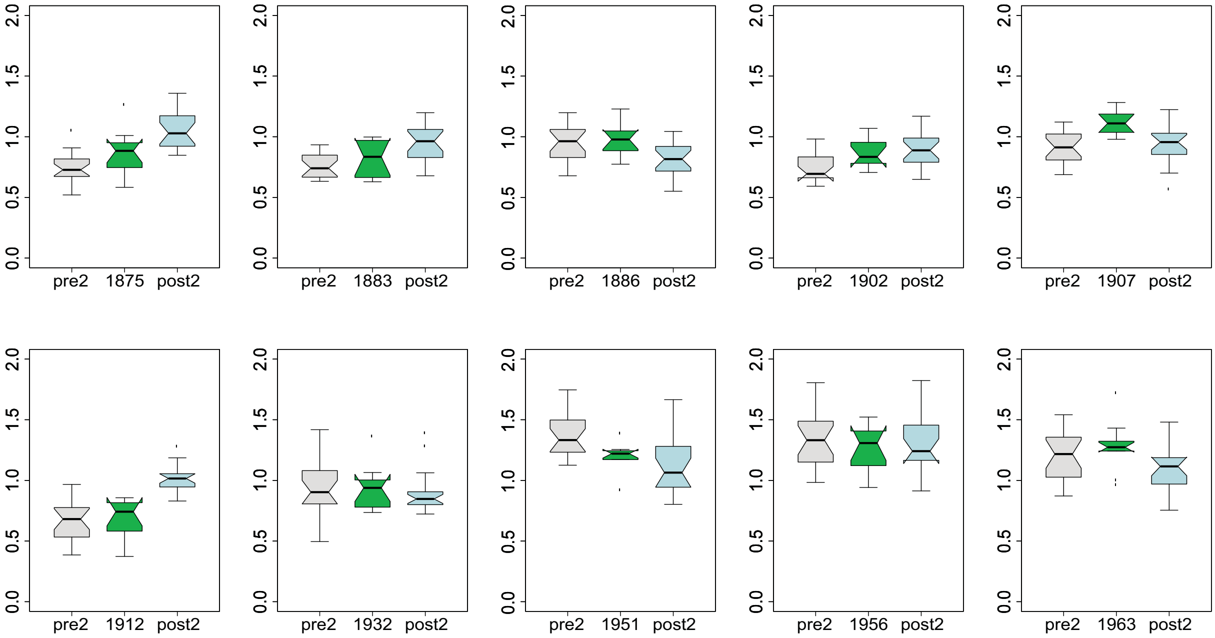


Figure 5: Example for boxplots analyzing the growth trends of standardized tree-ring series two years before and after volcanic outbursts during the period 1875-1963 for the site Quercus Greifswald. X-axis displays the year of eruption, two years before (pre2) and two years after (post2) a large volcanic eruption. Y-axis shows growth reactions of the standardized tree-rings series.

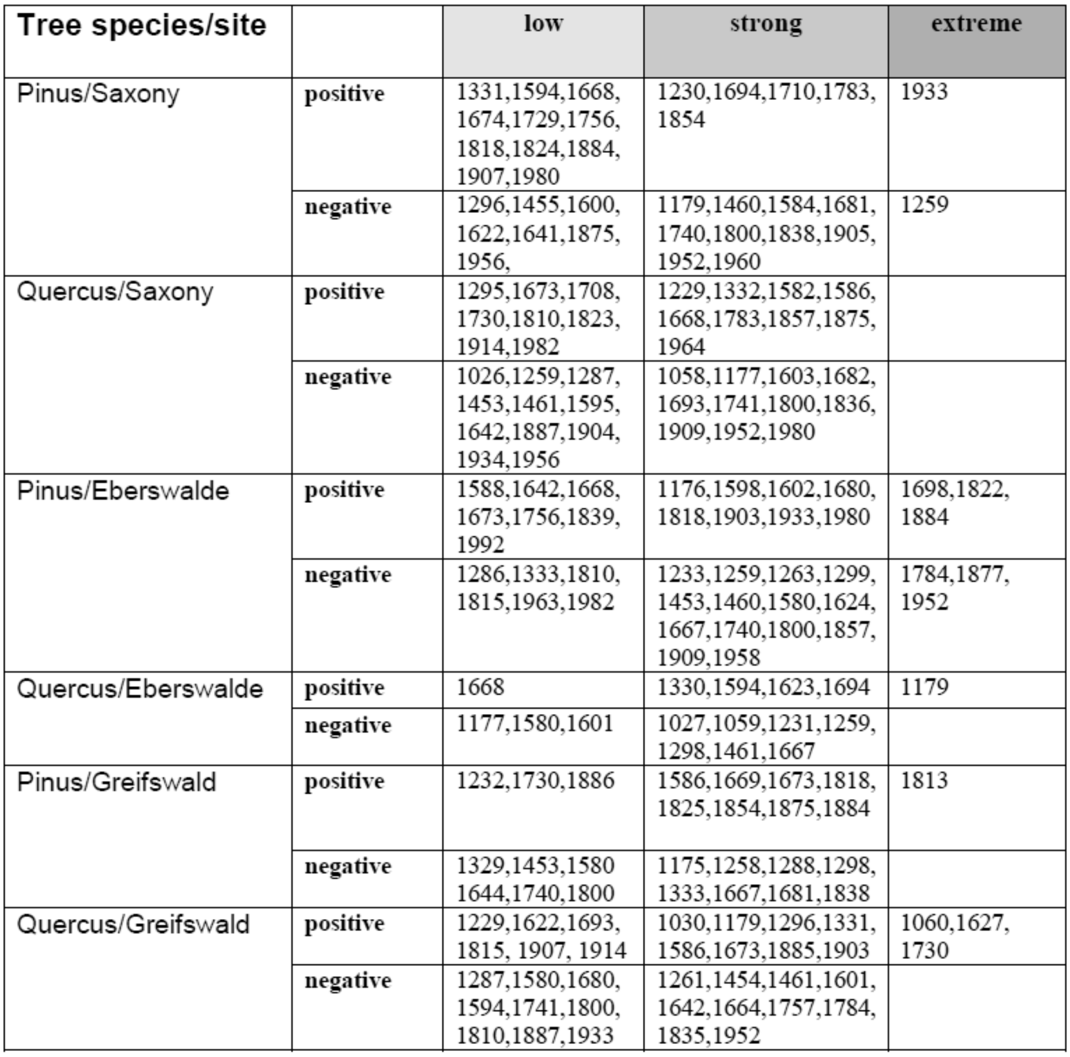
Through this analysis out of 225 possible cases 118 negative, 100 positive and 7 neutral growth trends after the volcanic outbursts were revealed. Thus, the impact of volcanic eruptions appeared to have a rather more negative influence and confirm the previous analysis (Fig. 4). When comparing both tree species *Q. robur* shows a tendency to more negative reactions than *P. sylvestris* which at Greifswald and Saxony displays mainly positive reactions as shown in table 2.

Table 2: Numbers of positive, negative and neutral tree-growth trends 2 years after each volcanic outburst sorted by tree and site. In brackets are the significant results. 46.5% of the P. sylvestris and 39.21% of the Q. robur results are significant (EW – Eberswalde, GW – Greifswald, SA - Saxony).

Growth-trend	Quercus EW (QE)	Quercus GW (QG)	Quercus SA (QS)	Pinus EW (PE)	Pinus GW (PG)	Pinus SA (PS)
positive	6 (2)	18 (8)	16 (2)	20 (10)	18 (4)	22 (11)
neutral	2	0	3	0	0	2
negative	13 (8)	24 (11)	25 (9)	22 (10)	15 (7)	19 (12)

By comparing all tree species at the three sites a relationship of 60% negative significant growth reactions and 40% positive reactions after the eruptions is shown. Slightly different results but with the same tendency are revealed by comparing the tree species at each site. QE, QS as well as PE and PS display 80% negative growth trends for *Quercus* and 50% for *Pinus.* In Greifswald, the growth trends are somewhat different, that is, with 58% and 64% negative growth response for QG and PG, respectively, only in Greifswald both tree species show a clearly negative response in tree growth after volcanic eruptions.

Table 3: Overview of the pointer years separated for tree species, locations and severity of the pointer years (low-1 standard deviation, strong-1.5* standard deviation, extreme-2* standard deviation)*



Tree species/site		**low**	**strong**	**extreme**
Pinus/Saxony	**positive**	1331,1594,1668, 1674,1729,1756, 1818,1824,1884, 1907,1980	1230,1694,1710,1783, 1854	1933
	negative	1296,1455,1600, 1622,1641,1875, 1956,	1179,1460,1584,1681, 1740,1800,1838,1905, 1952,1960	1259
Quercus/Saxony	**positive**	1295,1673,1708, 1730,1810,1823, 1914,1982	1229,1332,1582,1586, 1668,1783,1857,1875, 1964	
	negative	1026,1259,1287, 1453,1461,1595, 1642,1887,1904, 1934,1956	1058,1177,1603,1682, 1693,1741,1800,1836, 1909,1952,1980	
Pinus/Eberswalde	**positive**	1588,1642,1668, 1673,1756,1839, 1992	1176,1598,1602,1680, 1818,1903,1933,1980	1698,1822, 1884
	negative	1286,1333,1810, 1815,1963,1982	1233,1259,1263,1299, 1453,1460,1580,1624, 1667,1740,1800,1857, 1909,1958	1784,1877, 1952
Quercus/Eberswalde	**positive**	1668	1330,1594,1623,1694	1179
	negative	1177,1580,1601	1027,1059,1231,1259, 1298,1461,1667	
Pinus/Greifswald	**positive**	1232,1730,1886	1586,1669,1673,1818, 1825,1854,1875,1884	1813
	negative	1329,1453,1580 1644,1740,1800	1175,1258,1288,1298, 1333,1667,1681,1838	
Quercus/Greifswald	**positive**	1229,1622,1693, 1815, 1907, 1914	1030,1179,1296,1331, 1586,1673,1885,1903	1060,1627, 1730
	negative	1287,1580,1680, 1594,1741,1800, 1810,1887,1933	1261,1454,1461,1601, 1642,1664,1757,1784, 1835,1952	

The following pointer year analysis also confirmed the results of the previous analyses. The analysis identified 191 pointer years of which 106 were negative and 85 were positive pointer years. Common negative pointer years at all sites and of both tree species are 1258, 1453, 1663, 1739, 1800, 1951, 1956 and positive pointer years are 1586, 1667, 1673, 1822 and 1912.

For the eruption years 1229, 1815 and 1854 both tree species have similar patterns in growth reactions. In Greifswald and Saxony, both tree species show positive (low and strong pointer years) growth reactions after the eruptions. In contrast, trends to negative tree growth are suggested for *Q. robur* and *P. sylvestris* in Eberswalde (strong pointer years).

In the eruption year 1783 the two tree species in Greifswald show negative pointer years and in Saxony positive pointer years. Furthermore, in eruption year 1835 two negative and in 1854 two positive pointer years for Greifswald and Saxony are highlighted (Tab.3). However, we did not identify any extreme pointer years common to all three sites and the two tree species.

Dendrochronological analyses are a useful approach to distinguish the degree of growth reduction in *Q. robur* and *P. sylvestris* in eastern Germany due to volcanic eruptions. This work is a study on the effects of strong volcanic eruptions resulting in growth response on the local scale. This is an opportunity to explore the process and causal relationships between climatic changes and the response of the vegetation. Tree growth is limited by different factors, depending on the species and on the specific site conditions (Fritts 1976, Briffa et al. 1990, Briffa & Jones 1994, Mann et al. 1998, Hughes 2002).

Two hypotheses were considered in this study:

The first hypothesis dealt with the change in the radiation balance thereby cooling the atmosphere and leading to temporarily lower temperatures and a reduction of tree growth. Presumably a decrease in temperatures and an increase in relative humidity would lead to higher stomatal conductance and a possible decrease in photosynthetic rates. Ultimately, this will lead to a reduction of d13C and d18O values in the organic matter (Battipaglia et al. 2007, Krakauer et al. 2003). However, in this study no isotope data were analyzed, and thus, no stomatal conductance could be investigated to evaluate the impact of volcanic eruptions on net primary production. Visible signs would be decreasing tree-ring widths (Briffa et al.1988a, b, 1998a, b; Scuderi 1990; Jones & Bradley 1992). The hypothesis of a significant reduction in ring width following eruptions could be confirmed in this study. Comparable to results for tree species in southern Italy (Battipaglia et al. 2007) and northern forests (Krakauer et al. 2003) *Q. robur* showed in 70% of all cases and *P. sylvestris* in 54% negative growth trends at all three sites.

The second hypothesis, that is, enhanced photosynthetic rates and thus tree growth due to more diffusive light caused by volcanic ashes and aerosols in the atmosphere (Gu *et al.* 2003) could not be verified. Only a small proportion (30% of *Q. robur* and 46% of *P. sylvestris)* of the tree species analyzed showed positive growth trends. In these cases wider tree rings could be expected, with increased d13C values, and hardly changed or slightly lower d18O values, as a result of higher relative humidity and stomatal conductance, as suggested previously by Battipaglia et al. 2007.

However, a clear relationship between eruption magnitude, location of the volcanoes and tree-ring responses was not found. Not all large volcanic eruptions resulted in reduced tree growth in eastern Germany (Gervais et al. 2001).

In conclusion, volcanic eruptions seem to have a more negative influence on tree growth of *Q. robur* and *P. sylvestris* in eastern Germany, although the signal is not as clear and strong as has been found in previous studies (e.g., Briffa et al. 1998a). We identified more negative growth trends for *Q. robur* in comparison to *P. sylvestris*. The site Greifswald showed the most negative trends by comparing the growth trends of the trees from all three sites with each other. Volcanic eruptions of the northern hemisphere seem to have a more negative influence on tree growth of *Q. robur* and *P. sylvestris* in eastern Germany than volcanic eruptions of the southern hemisphere, although the signal is not as clear and strong as has been identified in previous studies for trees growing in more northern latitudes with comparatively longer negative growth trends of 10-20 years (e.g., Scuderi 1990, Shiyatov 1996, Briffa et al. 1998a, Jacoby et al. 1999, Gervais et al. 2001, Krakauer et al. 2003). In this study, negative growth trends of the trees lasted from 1-4 years.

For a comprehensive confirmation of the current results further investigations of other plant physiological parameters such as wood anatomical properties and stable carbon and oxygen isotopes of *Q. robur* and *P. sylvestris* and other tree species would be desirable.

Acknowledgments

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Age-related growth trends in ancient Norway spruce trees and potential effects on long term growth patterns

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Introduction

A long-term increase in radial tree growth has been reported in tropical (Lloyd & Farquhar 2008), temperate (Spiecker 1996, Voelker et al. 2006), alpine (Rolland et al. 1998) and boreal forests (Hofgaard et al. 1999) over the last decades. Variations in forest growth patterns have been ascribed to different causes, such as longer growing seasons due to climate warming (Hu et al. 2010), changes in land management practices (Hunter & Shuck, 2002), nitrogen deposition (Magnani et al. 2007), and atmospheric CO_2 enhancement (Voelker et al. 2006).

Tree-ring analyses provide detailed information on the past growth of forests. In order to assess the effect of climate change on forest growth, non-climatic variation should be removed from tree-ring series. The effect of endogenous (inter-tree competition) and exogenous (insects attacks, fires, storms, human influence, etc.) disturbances on tree-ring series can be detected and reduced by considering trees from different sites. Furthermore, as tree-ring width generally decreases as trees grow older and larger, age-related growth trend should be removed, to preserve climatic low-frequency variability of chronologies. Different detrending methods used to remove non-climatic variations need to be adapted to the objectives of a particular study.

A universally suitable estimation of the age-related growth trend cannot be developed (Briffa et al. 1996), as individual trees differ in growth rates along their life-span due to differences in environmental factors, stand dynamics, disturbances, etc. (Fritts 1976, Nicault et al. 2010). One of the more used methods in dendrochronology is the Regional Curve Standardisation (RCS) (Esper et al. 2003, Mitchell 1967). In this method, tree-ring series are aligned by cambial age, providing an expected age-growth Regional Curve (RC). The RCS method assumes that this curve describes the age-related growth trend of a population, and departures from the curve can be attributed to climate or other factors common to all trees (Esper et al. 2003). Several authors indicate that this method has specific limitations, mostly related to sample selection (Biondi & Qeadan 2008, Linderholm et al. 2010, Melvin 2004, Nicault et al. 2010). A necessary precondition for the application of RCS is to employ trees belonging to the same "biological growth" population, i.e. a group of trees with similar age-related growth trend (Esper et al. 2003). When fast and slow-growing trees are not equally distributed through time, significant biases can limit the interpretation of tree-ring chronologies (Biondi & Qeadan 2008, Briffa & Melvin 2011, Esper et al. 2003, Linderholm et al. 2010, Nicault et al. 2010). A few recent studies demonstrate an inverse relationship between growth rate and longevity (Bigler & Velben 2009, Black et al. 2008). This relationship should be considered, as it can affect long term growth trends, especially in chronologies composed of only living trees (Melvin 2004, Nicault et al. 2010).

In the present work we examined the radial growth of Norway spruce with respect to cambial age and calendar years. Increment cores from ancient and adult trees were collected close to the altitudinal forest limit in Trillemarka Nature Reserve, southern Norway. Dendrochronological analyses have been conducted (1) to evaluate growth trends along lifespan of different age trees and (2) to determine possible biases on long term growth trends using different age living trees. To achieve the second goal, we employed the RCS method. RCS assumes that Regional Curve describes the common age-related growth trend. However, if different age trees have different growth rates, unequal distribution of fast and slow-growing trees through time occur. Such pattern

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could affect long-term trends in index chronologies and, consequently, interpretation of growth patterns.

Material and Methods

The study area was located in Trillemarka Nature Reserve (60° 05' N, 9° 10' E), a protected area in southern Norway, between the valleys of Numedal and Sigdal, representing one of the last large and relatively undisturbed forested areas in southern Fennoscandia. The Reserve was established in 2002 and enlarged in 2008, today covering 147 km^2.

In order to sample the oldest Norway spruce trees in the forest, in 2003-2009 repetitive field surveys were conducted in old-growth Norway spruce stands close to the altitudinal forest limit (700-850 m a.s.l.), in an area extending 8 x 15 km. One or two (three) cores per tree were taken at 50-130 cm above ground level. Increment cores were shaved with a scalpel and treated with zinc paste to enhance tree-ring borders. Ring width was measured with a micrometer to the nearest 0.01 mm. Raw ring-width series were visually and quantitatively cross-dated against an existing site chronology (Storaunet, unpublished data) using TSAP (Rinntech, Heidelberg, Germany) and Cofecha (Holmes 1983) programs. 4 cores not reliably cross-dated were excluded from further analyses. For cores that did not include the pith, pith offset was estimated with a pith locator (Applequist 1958). The mean width of 10 innermost rings was used to estimate the number of missing rings (Groven et al. 2002). 9 cores with an estimated distance to pith >30 mm were excluded from further analyses. In order to calculate the total age of trees it was necessary to take into account the time to reach coring height. As cores were taken at different height above ground, estimated time varied between trees. Based on studies in similar forests (Storaunet, unpublished data), we estimated 2 years for each 10 cm of height. If two cores per tree were available, the core with more rings was used to estimate the age, while the core taken at breast height, or with less estimated distance to pith, was used for the analyses (Bigler & Veblen 2009).

93 individual tree-ring series were grouped in three classes according to estimated tree age: adult (130-230 years), old (230-350 years), and ancient (>350 years). We employed the RCS method to assess radial growth along cambial age and calendar years. As the pith offset may influence RCS (Linderholm et al. 2010), the number of years estimated to the pith and to sample height was added to the series, with a maximum of 59 and a minimum of 14 years. We calculated the Regional Curve (RC) as the arithmetic mean of ring widths for each cambial year for each age class, and for all series together. The RC was then smoothed using a cubic spline with a 50% frequency cutoff at 67% of the segment length (Leonelli et al. 2008). Index series were derived by calculating ratios between the measured ring width series and the RC. Mean index chronologies (IC) were calculated using the bi-weight robust mean, and were truncated at a replication of $n < 6$ series. ICs were smoothed with a 20-year cubic spline function to emphasize low frequency variations. Analyses were performed using Arstan (Cook & Holmes 1986).

Results and Discussion

Regional curves (RC)

Regional Curves of the three age classes show common age-related trends in ring width. However, growth rates appear to be different between the age classes, as the rings of adult trees were wider than those of old and ancient trees (Fig. 1). Recent studies show that trees have to grow slowly to reach very old age, particularly when competition scarcely affects growth (Bigler & Velben 2009, Black et al. 2008, Castagneri et al. unpublished). In our dataset, slow growth of ancient trees could be due to inverse relationship between growth rate and longevity. Indeed, juvenile growth rates of ancient trees were lower than those of old trees, even if these trees were established in the XVII and XVIII centuries, long before global warming. However, changing environmental influences cannot be excluded as a reason for these differences.

The all-RC is produced from the mean ring width of all chronologies aligned by tree age. However, adult trees only contribute to the young part of the all-RC, while the old part of the all-RC is formed only by ancient trees (Fig. 2). Therefore, the all-RC curvature is biased and produced not only by the age-related ring widths, but also by the differing growth rate of adult and ancient trees.

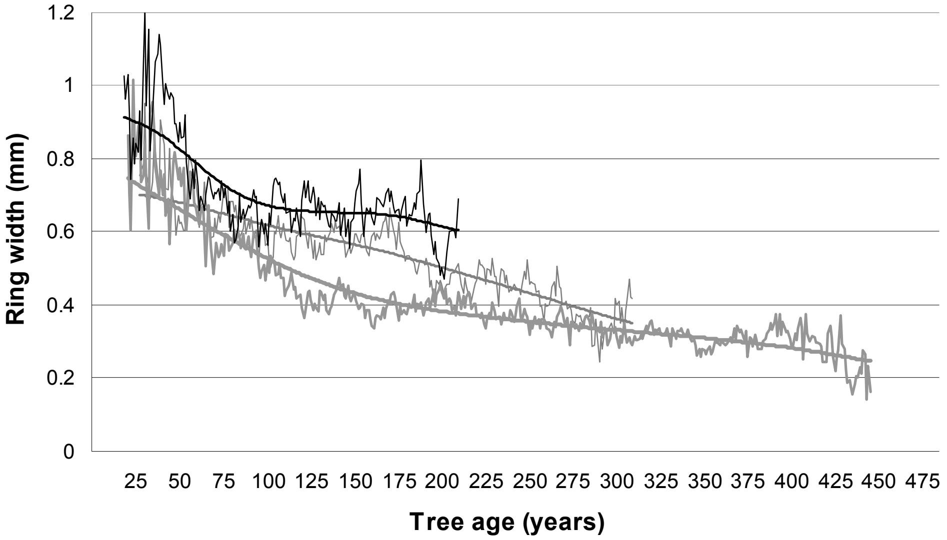

Figure 1: Regional Curves of adult (black), old (grey), and ancient (grey, bold) classes.

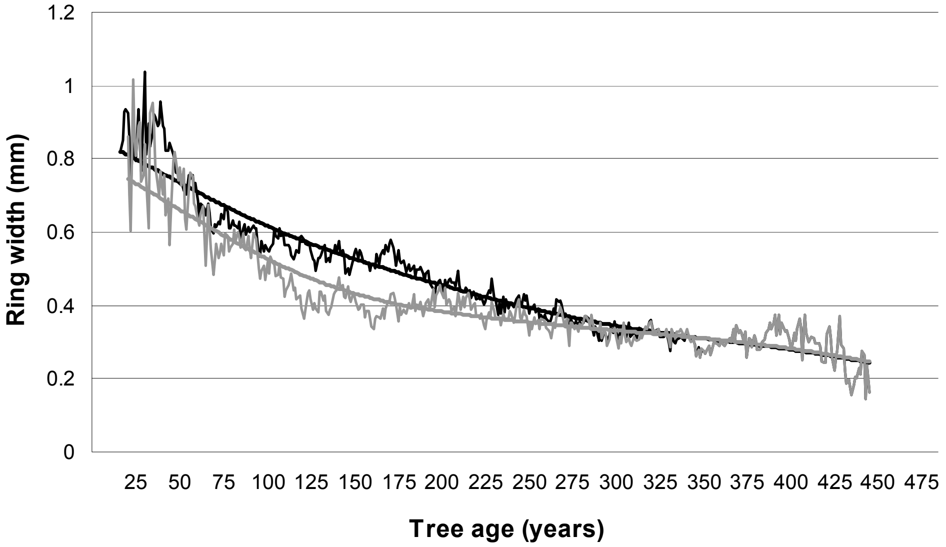

Figure 2: Ancient (grey, bold) and all (black, bold) Regional Curves.

Index chronologies (IC)

The Index Chronologies (IC) of the three age classes (adult, old, ancient) show multi-decadal variations, but no general increasing or decreasing trends (Fig. 3, 4). However, there is a positive long-term trend in the all-IC (Fig. 4), as ring width indices are mostly <1 before 1820 and >1 in the last century. Such trend results from an unequal distribution through time of slow and fast-growing trees. The early part of the all-IC derives from the ratio between the juvenile part of slow-growing ancient trees RW (which were young in 1600-1700, other trees were not yet alive) and the juvenile part of the all-RC, resulting in index values mostly <1. The recent part of the all-IC is influenced by the ratio between the juvenile part of fast-growing adult trees RW and the juvenile part of the all-RC, resulting in index values mostly >1.

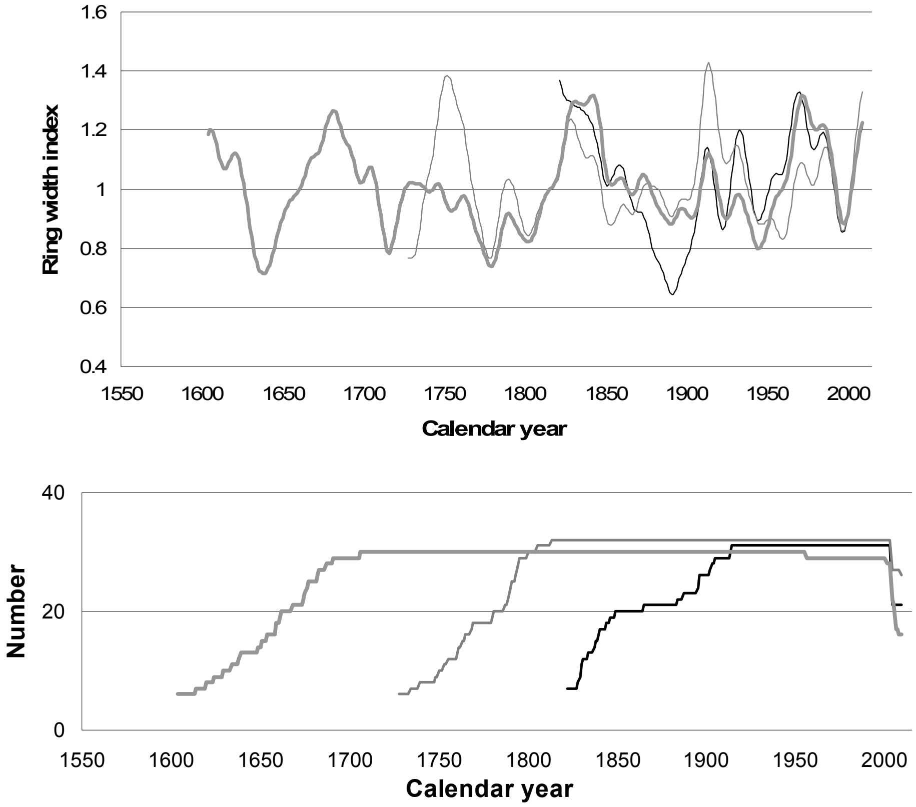

Figure 3: Index Chronologies (ICs) of adult (black), old (grey) and ancient (grey, bold) classes and sample size along calendar years. Series were smoothed with a 20-year cubic spline to emphasize low frequency variations.

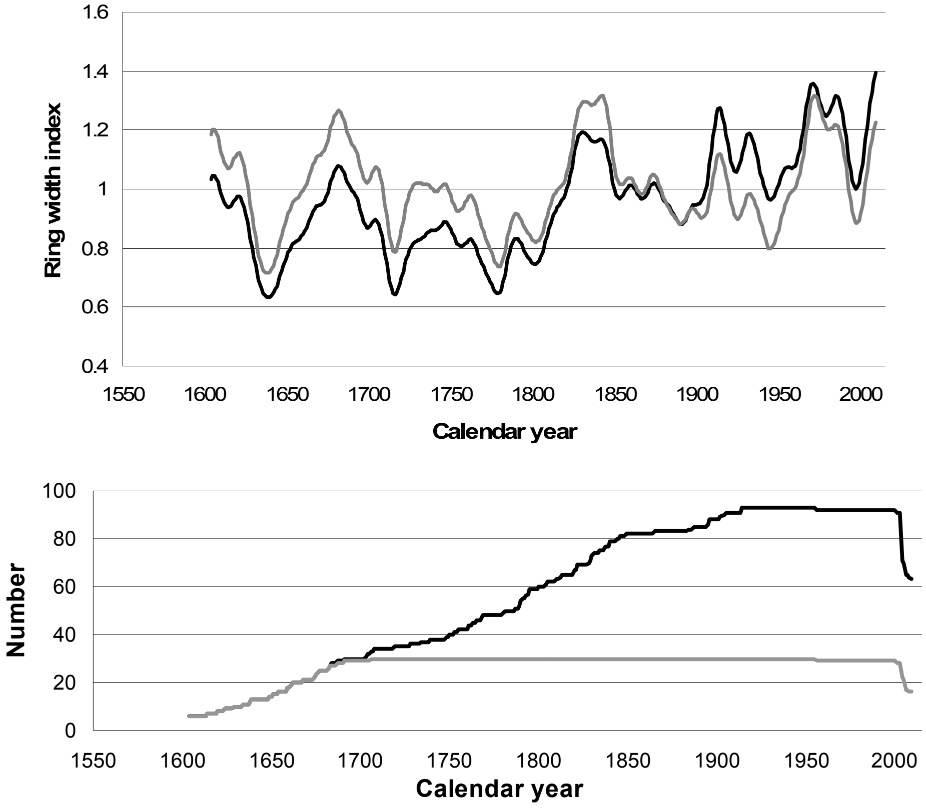

Figure 4: Ancient (grey, bold) and all (black, bold) Index Chronologies (ICs), and sample size along calendar years. Series were smoothed with a 20-year cubic spline to emphasize low frequency variations.

Conclusion

Regional Curves show that the oldest Norway spruce trees had lower growth rates than younger trees close to the altitudinal forest limit in Trillemarka forest. As sampled trees were established long before the global warming, influence of climate change on growth rates cannot be the only reason for observed patterns. A few studies suggest that such patterns are related to higher longevity of slow-growing trees (Bigler & Veblen 2009, Black et al. 2008, Briffa & Melvin 2011).

Applying RCS method to all series together, we obtained an Index Chronology with an increasing trend. Such trend was, at least partially, not related to climate change effect on tree growth. Fast-growing trees had low probability to reach old age, thus they could not survive long enough to be included in the early part of the chronology (Briffa & Melvin 2011, Melvin 2004). Therefore, this part was composed only by the oldest trees, which tend to grow slowly. The apparent increase in long term growth pattern resulted from associating growth rates of slow-growing ancient and fast-growing young trees. Indeed, Index Chronology composed solely by ancient trees did not show such trend.

Tree rings provide quantitative information on past forest growth. Radial growth trends have been widely investigated to assess long-term growth trends. However, while climatic reconstruction of past centuries use chronologies composed of living and dead material (Büntgen et al. 2005), many studies on forest growth trends have been conducted only on live trees (Bontemps et al. 2010, Rolland et al. 1998). Differently than short-term (annual) and medium-term (decadal) growth variations, long-term trends can be severely affected by age-related growth trends. Sub-fossil material in long-term records reduces biases, as young trees series can be included in the early part of the chronology. Further research is needed on that issue, and new methods (Melvin 2004, Melvin & Briffa 2008, Nicault et al. 2008) should be tested using different datasets.

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Age and growth of wild service tree (*Sorbus torminalis* (L.) Crantz) in former oak coppice forests in southwest Germany

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Introduction

Wild service tree (*Sorbus torminalis* (L.) Crantz) is a rare species, but not uncommon in oak coppice forests of Central Europe. Like other minority tree species, *S. torminalis* is of high ecological value and contributes to social welfare on numerous levels (LFV 1987, Spiecker 2006). Furthermore, the species is appreciated because of its wood, since only a few other European tree species yield comparable economical returns for high quality wood (Franke et al. 1990, Drapier 1993, Uthoff 2002, LÖBF 2004). Although *S. torminalis* is, from a forestry point of view, considered to be the most important species among the genus *Sorbus* (Heß 1905) it has rarely received consideration by forest management. Early publications refer to the species as of subordinate importance (Käpler 1805, Drais 1807, Weise 1888) or describe, like more recent publications, the need for species conservation (see e.g. Burckhard 1870, Bednorz 2007).

Wild service tree is wildly distributed across Europe, from the northern extremity of Africa to the south of Sweden and from the east of Great Britain to the north of Iran (Demesure-Musch & Oddou-Muratorio 2004). It grows on all types of soil and is a post-pioneer tree that colonises disturbed areas and forest edges (Demesure et al. 2000). The species shows also rather broad amplitude in terms of community context. It is mainly found in calcareous beech and hornbeam forests, but it also occurs in acidic oak forests (Rassumssen & Kollmann 2004).

Major reasons for the rarity of *Sorbus* species today are changes in forest management practice and increasing browsing pressure. Because of *S. torminalis* need for light forest management systems like coppice, with and without standards, are thought to have favoured minority tree species such as wild service tree over centuries (Rackham 1980, Kleinschmit 1998, Angelone et al. 2007, Pietzarka et al. 2009). Therefore, the creation of high forests, especially by transformation and conversion of coppice forests into high forests, is considered to be a reason for continuous species loss (Röhrig 1972, LFV 1987). For aged coppice forests, it is uncertain whether *S. torminalis* populations can persist in the longer term or whether coppicing is needed to maintain the species.

Against this background this study aims to determine i) if *S. torminalis* regeneration is dependent on coppicing and ii) if diameter and height growth of *S. torminalis* indicate that the species might be an inferior competitor when compared to its companion species, mostly sessile oak.

Material and Methods

Because the establishment of one coherent research site was impeded by small-scale changes of landscape form (and the subsequent changes of stand composition and management) three separate 1 ha sub-sites were established near the city of Baumholder (49°36′50″N, 7 20′0″E), in the federal state of Rhineland-Palatinate (southwest Germany). Site specific climatic, edaphic and geologic site conditions were summarized by Schneider (2004). The three sub-sites are located in former oak (*Quercus petraea*) coppice forests, in which silvicultural activities ceased following the last harvesting ca. 85 ago. The maximal distance between all plots was less than 1 km and there are no difference between the sub-sites in terms of species composition, former management and stand age. The occurrence of *S. torminalis* was no priority stand selection criterion because other coppicing related studies were carried out on the same sites (see Pyttel et al. 2008). In addition to

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oak, other woody species are *Carpinus betulus*, *Prunus avium*, *Fagus sylvatica*, *Pyrus pyraster*, *Sorbus aria*, *S. domestica* and *S. torminalis*. None of these species had been released from the surrounding oak competition through thinning or protected against browsing.

To obtain information about how many *S. torminalis* individuals had established after the last coppicing we quantified species frequency of all individuals > 1.3 m in height in each plot. To describe species growth, height and diameter measurements were taken for each *S. torminalis* individual and for a subsample of the surrounding oaks.

The contemporary age structure of the *S. torminalis* population was reconstructed from 80 stem discs cut at ground level in July 2009. Sample trees represented the diameter variation of the population inventoried on all three sub-sites. A master chronology for the study area was developed from lager *S. torminalis* trees to provide a dating control for all remaining samples (*sensu* Rozas 2003).

Ring-width series along four radial lines were measured to the nearest 0.01 mm using of a scanner in conjunction with WinDENDRO™ software. Cross dating was accomplished with both visual and calculative checking (Schweingruber 1983).

To reconstruct periodic diameter and height growth, 20 trees representing the populations' upper diameter limit were selected for stem analyses in combination with the counting of bud scale scars (Telewsky & Lynch 1991, Schweingruber 1996). Stem discs were cut at ground level, breast height and at 1 m intervals along the stem.

S. torminalis belongs to the diffuse- to slightly semi-ring porous woods and therefore offers a challenge for dendrochronology (Kahle 2004). In the sampled trees, the wood was very pale and it did not show contrasting coloration between early- and latewood. Partially absent rings (ring wedging) and indistinct year ring boundaries were common. The tendency of ring counting to underestimate age in *S. torminalis* trees was reduced by applying various methods of sample preparation. Year ring identification was improved with very fine polish and by using colorant (such as ordinary high lighters). Finally, questionable year rings were checked against microscopic analysis using microtome sections.

Results

On the three study plots, we found on average of 241 *S. torminalis* trees per hectare. In total 724 individuals higher than 1.3 m were inventoried. The number amount of *Q. petraea* individuals amount totals on average 1377 trees per hectare. Percentage of *S. torminalis* trees on total stand tree layer ranged between the sub-sites from 1.4 to 4.3 until 6.3%.

Mean DBH of all recorded *S. torminalis* trees was 6.6 cm. Even 85 years after the last coppice cut DBH of almost 65% of all inventoried wild service trees was below the solid wood threshold of 7 cm (Fig. 1a). Corresponding to the high number of trees with low diameters, most of *S. torminalis* trees were smaller than 10 m in height. Only few wild service trees reached a height of 15 meters or more, while most oak trees were higher than that. Consequently, sessile oak was the common tree species in the upper tree canopy (Fig. 1b).

Age determination showed that tree age within the *S. torminalis* population varied (Fig. 1c, 2). Most of the trees established over a period of 70 years before destructive sampling. Only a few trees were found to be younger than 19 or older than 80 years. As few as six trees older than 70 years were found. Interestingly, many of the trees with a diameter below 7 cm were older than 40 years (Fig. 1c). However, no distinct establishment phase was identified.

Stem analyses showed that average radial increments at 1.3 m height ranged between 1.9 and 2.2 mm during the first 8 years after tree establishment (Fig. 3a). Thereafter, radial increment of all trees decreased continuously with increasing tree age. Until a tree-age of 25 years, the average radial increment dropped below 0.7 mm and remained fairly constant until the time of sampling. At the individual tree level, increment of some trees surged spontaneously and far above the average. These positive growth trends lasted for a few years until growth declined again to an average level.

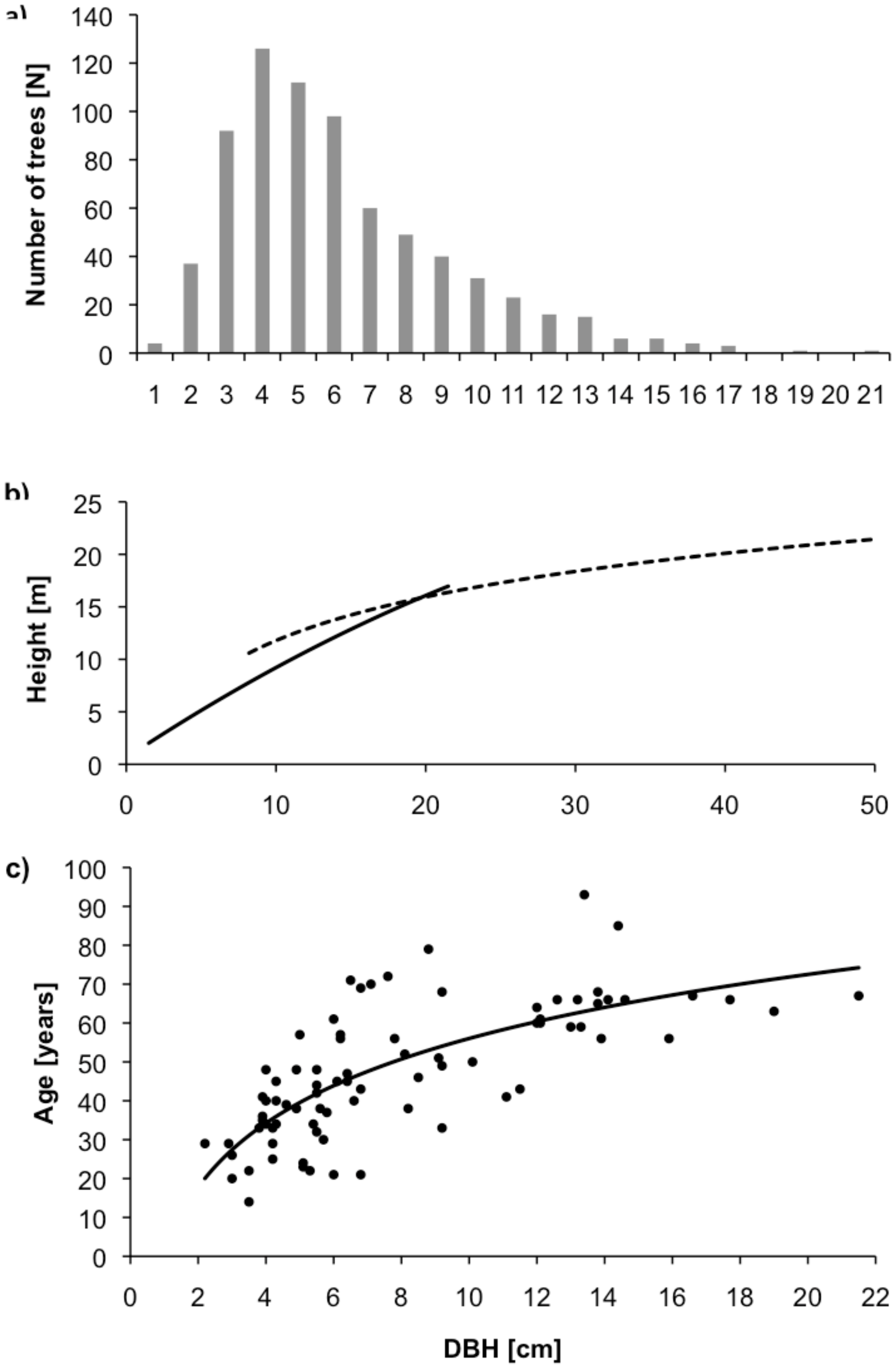

Figure 1: a) Diameter distribution of Sorbus torminalis *trees over all study plots (N=724, DBH classes cluster trees with same pre-decimal position).b)Tree height in relation to diameter at breast height (DBH) of* S. torminalis *(N=678) in comparison to Q. petraea (dashed line, y = 6ln(x) – 2.022, R² = 0.61, N=112) and c) relation between tree age and DBH of wild* S. torminalis *(y = 23.78ln(x) + 1.28, R²= 0.53, N=80).*

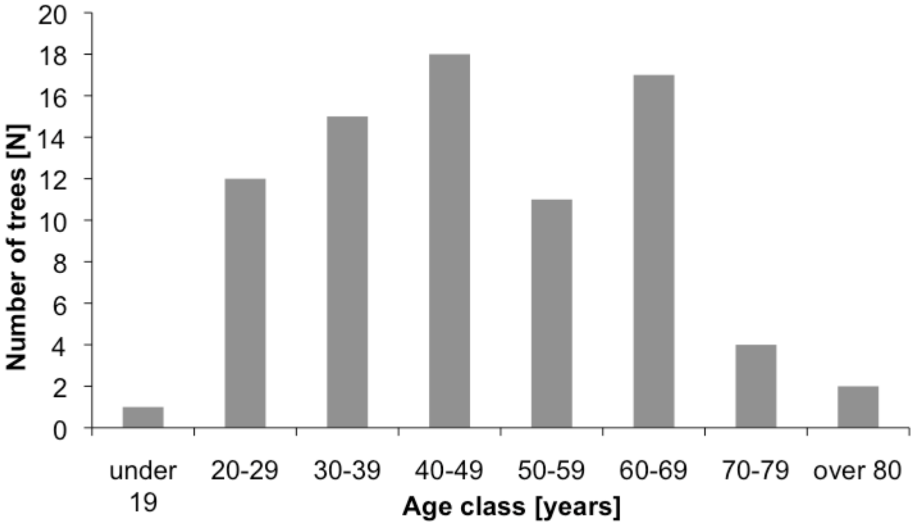

Figure 2: Age structure of S. torminalis *(N=80) in a former oak coppice forest. Trees younger than 19 and older than 80 years are summarized.*

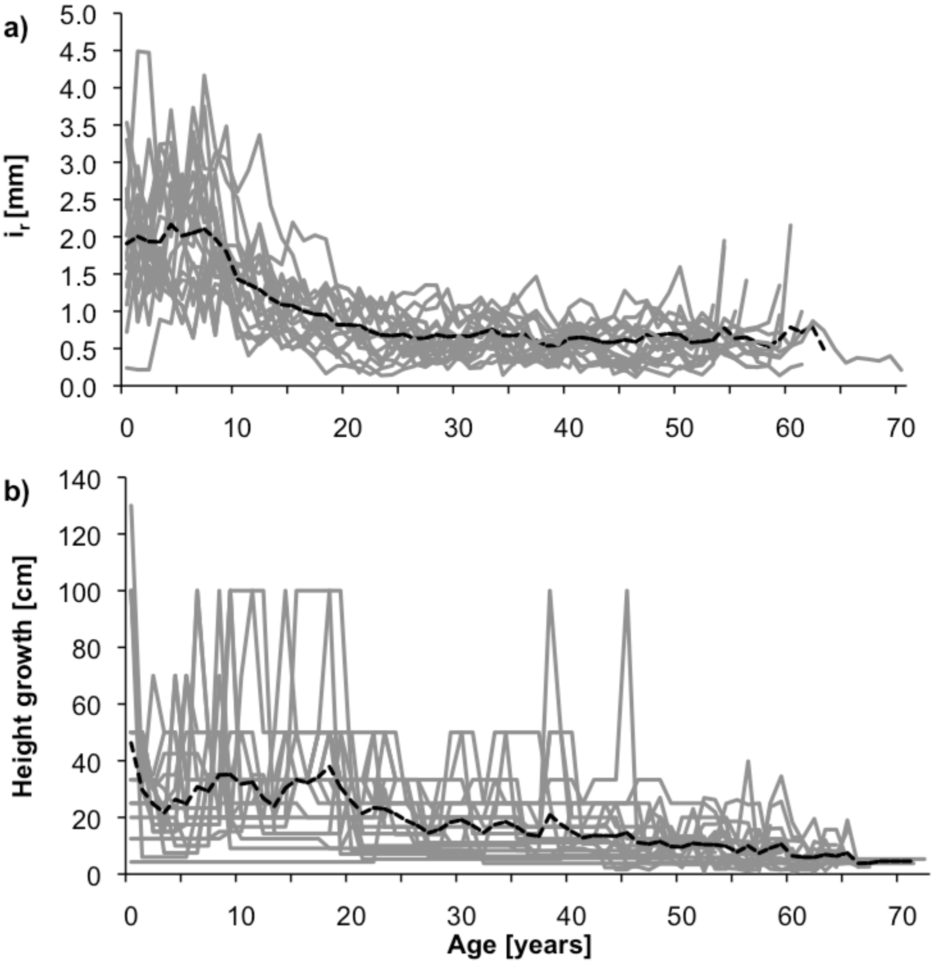

Figure 3: a) Radial increment measured at 1.3 m height and b) height increment in relation to tree age of Sorbus torminalis *grown in aged oak coppice forests. Grey lines indicate increments of single trees, the dashed black line shows the mean of all sampled trees (N=20).*

Average height increments fluctuated between 21 and 43 cm per year until the trees were 18 years old (Fig. 3b). During early growth phases, individual trees reached annual height increments of 1.3 m. In the subsequent years, mean height increment declined strongly, a pattern comparable to that of radial growth. However, changes in height growth were less abrupt. With increasing tree age, mean height increment declined to a level of only 5 cm at the age of 70 years. However, short burst in height increments of 50 and 100 cm were observed for individual trees in later growth phases.

As expected, growth of *S. torminalis* depended on canopy position (Fig 4). In accordance to Kraft's classification, co-dominant trees showed a comparably strong growth in the first decades after establishment. As in the given example, phases of reduced radial and height increment can follow (Fig. 4a). However, 50 years after establishment, co-dominant trees can show a consistent increase in radial growth increment along the whole stem axis.

The effect of tree suppression through competition is indicated through the continuously decreasing height and radial growth (Fig 4b). The co-dominant tree reached its final height of 10 m after 35 years, while it took the suppressed tree 55 years to reach a height of 9 m. Persistence or life expectancy was found to be independent of canopy position. Even suppressed trees persisted over a long period under the canopy of surrounding oaks.

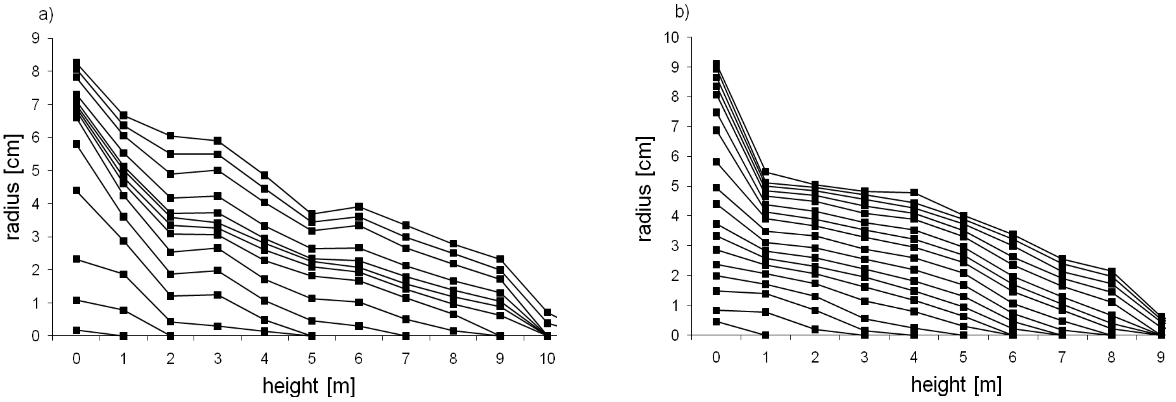

Figure 4: Height growth in relation to diameter increment of a) one co-dominant and b) one suppressed S. torminalis *tree. Lines represent 5 yearly increment periods.*

Discussion

Because *S. torminalis* is considered to be a rather rare tree species, the number of individuals > 1.3 m found in the studied aged oak coppice stands was surprisingly high. Age determination of trees indicated that that continuous recruitment of *S. torminalis* regeneration occurred over the last 80 years. Together, these data provide little support for the hypothesis that coppicing itself promotes the establishment of new *S. torminalis* cohorts. Obviously, the species has the capacity to establish beneath a closed canopy.

After 25 years, average annual radial increment of the studied trees dropped to 0.7 mm and remained constant. This growth reduction is far lower and more prolonged than reported previously (Hochbichler 2003, Kahle 2004). In those studies *S. torminalis* grew in high forests and was tended. No such measures took place at the research sites of this study, leading to impaired growth with increasing tree age and subsequent suppression. This is consistent with findings by Leder & Kahle (1998), who observed that natural growth potential of *S. torminalis* is often limited by concurrent tree species.

The average height increments during the first 20 years after tree establishment confirm findings of Röhrig (1972), Bamberger (1990) and Schüte (2001). However, bursts in height increments or sudden growth changes decades after tree establishment (see Fig. 3b) indicate that even after enduring phases of suppression, increased height and radial growth can be observed. These spontaneous height and (less distinct) radial increments are neither related to tree age nor to silvicultural measures but presumably to changes in growth conditions through increased growing space. Thinning-induced growth increments of 80 to 100 year old *S. torminalis* trees were documented by Elflein et al. (2008). This late responsiveness is consistent with the results of this study but restricted to trees of co-dominant or dominant canopy positions (see Fig. 4).

We conclude that the status of *S. torminalis* is not threatened in the observed stands, ca. 85 years after the last coppicing. Furthermore, observed growth patterns confirm that *S. torminalis* is an extremely shade tolerant species that can survive long periods of intensive competition. In the absence of silvicultural measures, the fate of individual *S. torminalis* trees may depend on the frequency of disturbances and the duration of periods of release versus suppression.

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Growth and Nutrition Status of Spruce (*Picea abies* (L.) KARST.) in Mountain Regions with Different Nitrogen Load Levels

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Introduction

Forests in the northern part of the Czech Republic were highly influenced by the air pollution (SO_2, NO_x) till the end of the 1980ies. By the end of the 1990ies the SO_2 emissions were reduced by nearly 90% (Fiala et al. 2002). Nevertheless the nitrogen (N) deposition remained at high level – mean total annual N-deposition exceeded 25 kg.ha^{-1} in this area (Lochman et al. 2004).
During 1999 - 2002 severe damages have been recorded within the spruce stands in the Orlické and Krušné Mountains (Czech Republic). In the Orlické Mountains mainly young spruce stands showed symptoms of damage (e.g. drying of terminal shoots, or dieback of the upper part of the crown), whereas in the Krušné Mountains widespread yellowing of spruce stands of all age classes occurred (Šach et al. 1999, Lomský & Šrámek 2004, Čermák et al. 2005). Spruce growth, however, was not affected negatively; young spruce stands showed extraordinary high height increments (Vejpustková et al. 2004). The impact of N-deposition was hypothesized.
This study aimed at the analysis of growth trends of Norway spruce (*Picea abies* (L.) KARST.) in a problematic region (Orlické Mountains, western part of Krušné Mountains) and in Žďárské Vrchy as a control locality (mean total annual N-deposition about 10 kg.ha^{-1}). At the same time as the deposition measurements, soil chemistry and nutrition amount in needles was measured to provide insight into the nutrient cycling.

Material and Methods

The Orlické and Krušné Mountains are situated in the northern part of the Bohemian Massif. The control locality Žďárské Vrchy belongs to the Czech-Moravian Highlands and it is located in the central part of the Bohemian Massif (Fig. 1). The localities were selected to represent similar site and climatic conditions (Tab. 1). Spruce stands on poor sites with a share of spruce of more than 80% were included. In the Orlické and Krušné Mountains stands exhibiting yellowing or other types of damage were preferred.

Table 1: Position and characteristics of the study sites

Region,	**Position**		**Altitude**	**Soil**	**Mean annual Temperature (°C)**	**Sum of annual Precipitation (mm)**
Locality	**N Lat**	**E Long**	**m a.s.l.**	**type**		
Orlické Mts., Šerlich	50°16'	16°23'	870-1010	podzol	5,4	1196
Krušné Mts., Přebuz	50°23‘	12°36‘	880-940	podzol	5,7	800
Žďárské Vrchy, Čachnov	49°43'	16°04'	680-775	cambisol	5,8	765

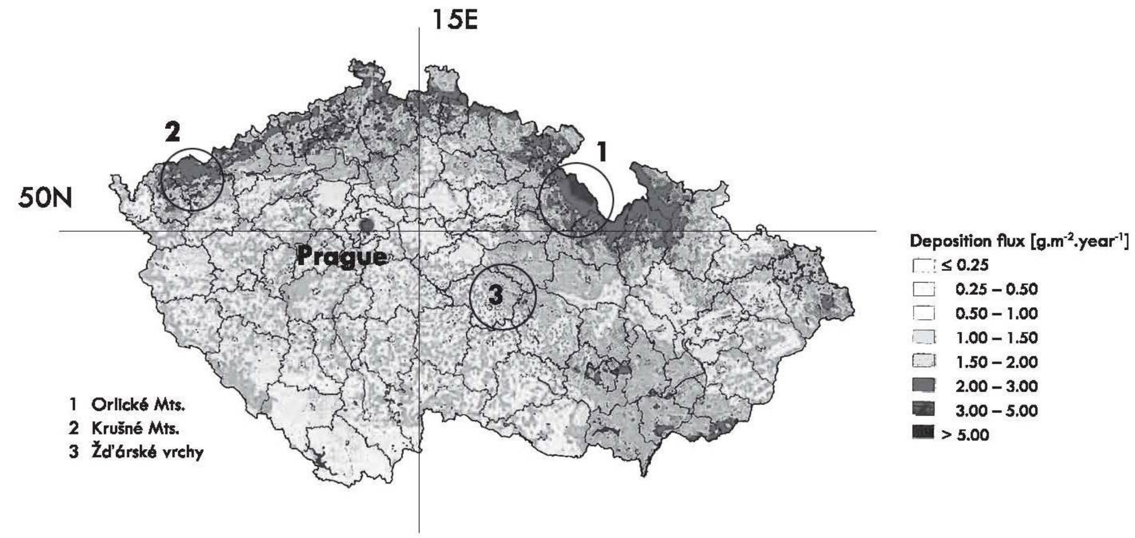

Figure 1: Map of total annual nitrogen deposition in the Czech Republic in 1999. Circles: location of the study sites.

Norway spruce growth was examined by means of detailed stem analysis of 10 sample trees of one mature spruce stand (age 120 years and more) in each region and height growth measurement of at least 400 spruce trees at the age of 10 to 50 years in each region. Sampling and growth measurements were done in the period 2002 – 2004.

For the stem analysis 10 dominant trees were cut in the mature spruce stand. First stem disc was taken in the height of 130 cm above ground (DBH), other discs then in two-meter sections. Radial increments were measured at each stem disc along 4 radii. Ring-width measurement was done using measuring table Kutschenreiter, with an accuracy of 0.01 mm. Individual ring-width series were visually cross-dated, dating was verified statistically with the COFECHA program (Holmes 1983). Verified series were used to state a height growth of the trees, derived as an average height increment in corresponding stem section, as a quotient of the section length (2 m) and the difference of tree-ring number at the beginning and the end of two-meter section.

The ring-width series of breast-height discs were standardised to eliminate the age trend with the program ARSTAN (Holmes et al. 1986). The resulting index series were aggregated by calculating mean values into the local chronology.

Height growth of the young stands was determined by measuring the annual internode lengths on an individual tree basis beginning from the tree top. For further evaluation the young stands were divided into 4 groups according to the age classes: (1) 10 – 20 years, (2) 21 – 30 years, (3) 31 – 40 years, (4) 41 – 50 years. The mean height growth curves for individual age classes were plotted.

Atmospheric deposition, soil chemistry, forest nutrition

The growth patterns in three regions investigated can be characterized by the different levels of nitrogen deposition and different quality of forest nutrition. Relationship of growth to nitrogen input was analysed in the regions of Orlické Mountains and Žďárské Vrchy, where the atmospheric deposition data were at disposal for the period 1993 - 2001.

Analysis of the soil chemistry was done in each region in the mature Norway spruce stand. Soil samples were taken in the whole profile, by genetic horizon. In the samples exchangeable amount of nutrients were stated (Al, Ca, Fe, K, Mg, Mn, Na, Zn) extracted in NH_4Cl, pseudototal element amount (Al, Ca, Fe, K, Mg, Mn, Na, Pb, S, Zn) in *Agua regia*, pH $_{(H_2O)}$, pH$_{(KCl)}$, total amount of C, N, and S, exchangeable P and dry mass stated.

Nutrition of trees was illustrated by chemical analyses of the foliage. Mixed samples of needles of individual needle year classes were melted in a mill of titanium head; then samples were decomposed in nitrogen acid and hydrogen peroxide in microwave system MDS 2000. Amounts of P, K, Ca, Mg, Fe, Mn, B, S were stated at ICP-OES, nitrogen at CNS analyzer.

Results

Norway spruce growth

The mean ring-width chronologies of mature sample trees show high coincidence in inter-annual variation (Fig. 2). It can be supposed that the growing conditions are comparable at the study sites and tree response is similar.

After 1970 a major growth depression with minimum increment in the period 1980 – 1986 was observed in Šerlich (Orlické Mts.) and Přebuz (Krušné Mts.). Afterwards a sharp growth increase since 1987 in Šerlich and Přebuz, and since 1997 also in Čachnov (Žďárské vrchy) is indicated (Fig. 2).

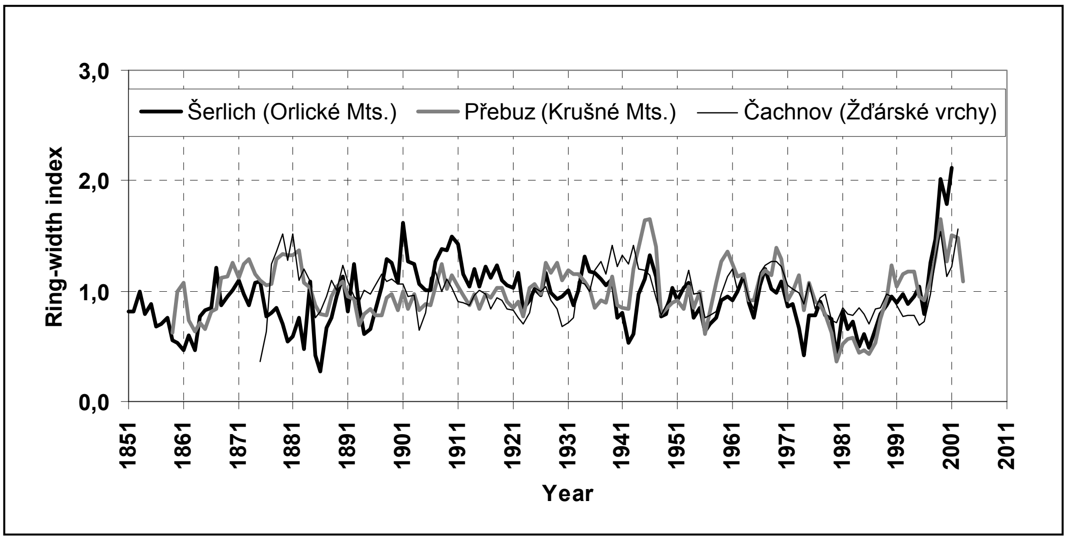

Figure 2: Ring-width chronologies of mature spruce trees.

Tree height of mature sample trees is increasing constantly; typical flattening of the height growth curve in mature age is not visible (Fig. 3). In the plots Přebuz and Čachnov the trend of height growth is almost linear over the whole lifespan of the trees.

The shift in the height curve levels was proved for the young stands (10 – 50 years of age) (Fig. 4). A significant increase of height at tree age of 15 years was found in the period 1975 – 2001. The trend was of the magnitude 1,3% per year in Žďárské vrchy, 2% per year in the Krušné Mts. and 7% per year in the Orlické Mts.

For mature spruce trees correlation analysis did not prove positive relation of growth to nitrogen inputs neither in Orlické Mts., nor in Žďárské vrchy. By contrast, for young spruce trees a significant positive correlation of annual height increment with annual wet nitrogen deposition rates was found in both regions.

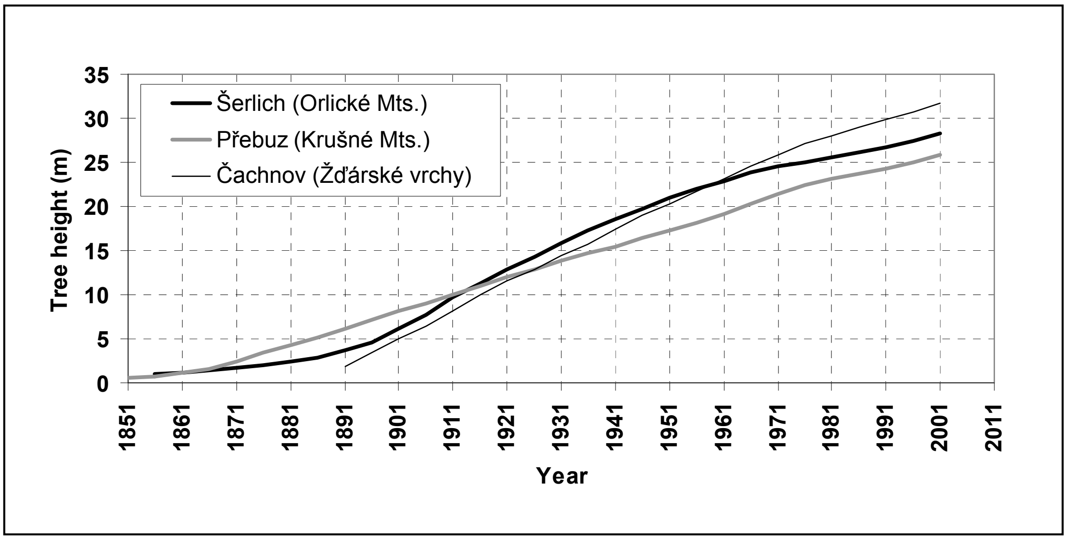

Figure 3: Height growth of mature spruce trees

Soil chemistry, nutrition amount in needles

In the localities Šerlich, Přebuz and Čachnov the soil chemistry can be classified as disturbed (Tab. 2). The values of active pH$_{(H_2O)}$ and exchangeable pH$_{(KCl)}$ confirm high acidity of the soil in all horizons (pH<4). Nitrogen amount in the soil was the highest in Šerlich, in the whole soil profile. High N concentrations even in deeper soil horizons (0,19% in 30 cm) confirm saturation of the humus and upper mineral soil layers by nitrogen, and it seems to be probable, that N is leached to deeper horizons. All studied plots exhibit significant deficit in the exchangeable calcium (<140 mg.kg^{-1}) and magnesium (140 mg.kg^{-1}) contents in the mineral soil. Most severe is this deficiency at Přebuz, where the exchangeable calcium reach only 7.8 mg.kg-1 and magnesium 2.35 mg.kg-1 in the upper mineral soil (ca. 0-30 cm). Exchangeable potassium is low (< 30 mg.kg^{-1}) in mineral soil at Šerlich and Přebuz.

Norway spruce nutrition, characterized as the results of the foliar analyses (Tab. 2), is most problematic at Přebuz exhibiting low or deficit content of nitrogen (< 1,3%,), phosphorus (< 1200 mg.kg^{-1}) and magnesium (< 700 mg.kg^{-1}) in mature stands and of potassium (< 3000 mg.kg^{-1}), calcium (< 2500 mg.kg^{-1}) and magnesium in young stands. Phosphorus and magnesium deficiency was identified also in the mature Norway spruce stand in Čachnov The nitrogen content in needles is good in both localities Čachnov and Šerlich. In Orlické Mts. also the supply of other nutrients is generally also good or sufficient.

Table 2: Soil and needle analysis – summary of results

	Šerlich (Orlické Mts.)	**Přebuz (Krušné Mts.)**	**Čachnov (Žďárské vrchy)**
Soil analysis (in mature stands only)	high content of N, sufficient content of P, **deficit of K, Ca, Mg,** intensive nitrification	**deficit of N, P, K, Ca, Mg**	sufficient content of N, P, K, **deficit of Ca, Mg**
Needle analysis in mature stands	good nutrition of N and P; sufficient nutrition of K, Ca, Mg	sufficient nutrition of K, Ca; **deficit of N, P, Mg**	good nutrition of N, K, Ca; **deficit of P, Mg**
Needle analysis in young stands	good or very good nutrition of N; other elements good or sufficient nutrition	good nutrition of N; **deficit of K, Ca, Mg**	*no analysis*

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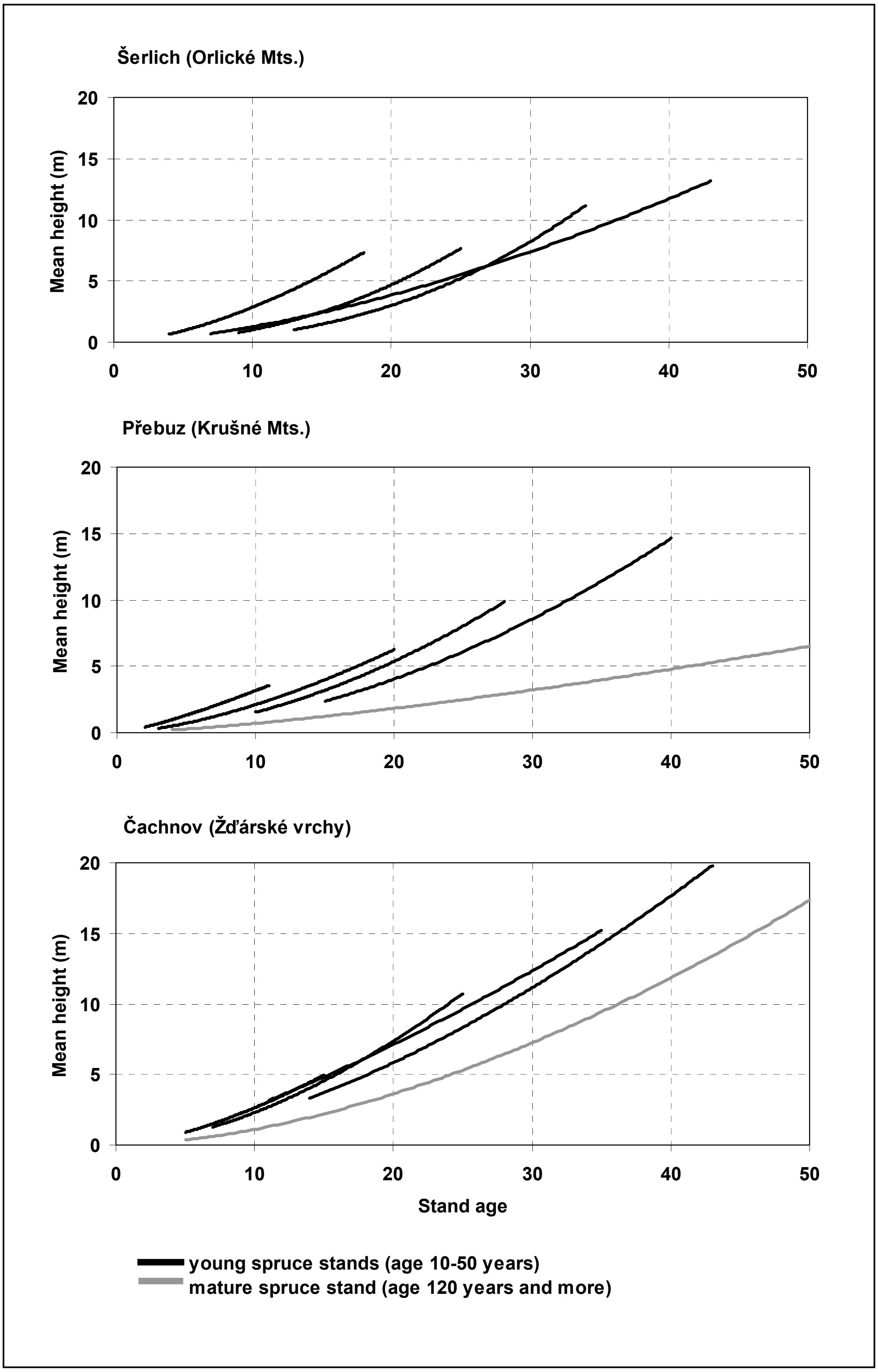

Figure 4: Height growth of young spruce stands.

Discussion

Growth depression since the mid-seventies to mid-eighties of the last century is typical for the mature spruce stands in mountain regions along the northern border of the Czech Republic (Kroupová 2002, Kroupová & Kyncl 2001, Röhle 1999, Sander et al. 1995). These authors confirm, at the same time, stand recovery at the end of eighties. Growth decrease was explained by climatic extremes in coincidence with high air pollution load at the end of the seventies and in the first half of the eighties (Kroupová 2002, Materna 1999).

Growth increase of mature spruce trees in Orlické Mts. and Krušné Mts. corresponds to lowering of the air pollution load since the end of eighties (mainly SO_2) and suitable climatic conditions. Analysis of the climatic data of the stations Deštné (Orlické Mts.), Nová Ves (Krušné Mts.) and Svratouch (Žďárské vrchy) confirms the upward trend of mean temperatures during the vegetation period. Mean vegetation period temperatures in 1992, 1994, 1999 and 2000 are among the highest in the period of measuring within the all stations. High temperatures in vegetation period were connected to low precipitation amounts in 1988 – 1994. In contrary, the vegetation seasons of 1995 – 1998 were above-average in precipitations. Growth increase in Šerlich and Přebuz after 1986 thus corresponds to warm summers; drought at the beginning of nineties did not effect the growth. Spruce in Čachnov can be sensitive to water deficit in summer period, and this may be the reason, why the sharp growth increase was observed only in 1997 – 2001 here.

Results of the soil and needle analysis confirm higher nitrogen saturation of the plot Šerlich, and, in the same time, they document serious disturbance of nutrition in the plot Přebuz. These findings do not correspond in expected way with the results of the stem analyses. Acceleration of diameter increments and also basal area and volume increments is comparable in both localities. It seems to be probable, that impact of nitrogen inputs on tree growth of the mature spruce trees is limited.

The shift in the level of the height curves of the young spruce stands in Orlicke Mts. and Krušne Mts. can be interpreted as a proof of ongoing fast changes of the growing conditions in the last 50 years. Wenk and Vogel (1996) analysed the trends of the top height of the spruce stands of different age. They proved greater steepness of the height curves with younger stands. Maximal difference among the curves of today young stands and the oldest stands was recorded at the age from 40 to 80 years; afterwards the height curves converge again. Elfving and Tegnhammar (1996), on the base of repeated measurement of pine and spruce sample trees within the national forest inventory in Sweden in 1953 – 1992, proved, that the tree height at given age significantly increases within this 40-year period, from 0.6 to 0.8% per year for these two tree species. These values are highly over-exceeded in the young stands of the localities studied in the Czech Republic.

Compared with low nitrogen amounts in needles in the mountain regions of the Czech Republic at the beginning of eighties (Materna 1986), in the nineties significant improvement of nitrogen nutrition of the young spruce stands was observed, both in Orlické (Šrámek et al. 2001) and Krušné Mts. (Lomský, Šrámek, 2004; Lomský et al. 2006). Thus it seems to be probable, that growth acceleration of the young stands in the last decade is connected not only to suitable climatic conditions in this period, but also to higher nitrogen inputs. This hypothesis is supported also by abnormal height growth rate of the youngest stands in the Orlické Mts., where, contrary to the Krušné Mts., better nutrition of nitrogen is not connected to significant deficiency of other basic elements.

Conclusions

Growth increase of mature spruce trees in Orlické Mts. and Krušné Mts. corresponds to lowering of the air pollution load since the end of eighties (mainly SO_2) and suitable climatic conditions. No relationship to N-depositions was found. Results of the soil and needle analysis confirm higher nitrogen saturation of the plot in Orlické Mts. and, in the same time, serious disturbance of nutrition in Krušné Mts. Nevertheless acceleration of volume growth is comparable in both regions.

The shift in the height curve levels of the young spruce stands can be interpreted as a proof of ongoing fast changes of the growing conditions in the last 50 years. It seems to be probable, that growth acceleration of the young stands in the last decade is connected to high nitrogen inputs. The hypothesis is supported also by abnormal height growth rate of the youngest stands in the Orlické Mts. where, contrary to the Krušné Mts., good nutrition of nitrogen is not connected to significant deficiency of other basic elements.

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Using photomanipulation to facilitate the cross-matching of difficult species for dendrochronological research

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Introduction

This paper describes the procedure developed to apply dendrochronology to an endemic New Zealand tree species which presents several fundamental challenges (see figs 1&2). “Cross-dating is the most important principle of dendrochronology” (p.20, Fritts, 1976) and depends on the identification of similar variations of growth parameters, such as annual ring widths, within trees and between trees across an area. Although many approaches exist to achieve this, where New Zealand species are concerned, Norton & Ogden (1987) recommend a visual based approach to cross-dating because of the frequency of anomalous tree rings. This new approach to visual cross-dating is computerised, it uses scanned images of the prepared cores, and adapts the technique of skeleton plotting based on Schweingruber, Eckstein, Serre-Bachet & Bräker (1990).

There have been no published cross-dated chronologies using Kahikatea (*Dacrycarpus dacrydioides),* a New Zealand native *Podocarpaceae* species and authors, e.g. Bell & Bell (1958), Cameron (1960) and Stewart, Norton & Fergusson (1991) have all commented on the difficulties posed by lobate growth causing wedged and locally absent rings. Stewart *et al.*, 1991 avoided the annual resolution problem when investigating heavy metal accumulation in the species by using blocks of ten tree rings. Although not annually resolved, Stewart *et al.* (1991) showed the synchronous increase of heavy metals related well to the known historic increases in industrial activity. Stewart et al. (1991) thus support the assumption that the tree rings in this species are predominantly annual, albeit with anomalies.

Patel (1967) describes the growth rings themselves as “indistinct to slightly distinct, occasionally distinct” while Dunwiddie (1979) states that rings had good clarity. Dunwiddie (1979) notes that lobate growth is less with younger trees, and considered the species worthy of more detailed investigation. This current study used a range of tree size classes to control for the problem of lobate growth. We found sufficient variability in the samples to justify both of these opposing descriptions, although in general Dunwiddie’s viewpoint is favoured. Often ring clarity was poor (see figures 1 & 2), either very faint or obscured within broad bands of late wood. Missing and wedged rings were identified and false rings (sub-annual rings), as described by Norton & Ogden (1987), were also observed. However these problems have not precluded dendrochronology but rather have catalysed the development of suitable and specific methods.

This digitalised approach to dendrochronology enables new methods and techniques. Photo-enhancement improves the visibility of faint tree rings (see figure 1), enabling ring border identification. Tree ring width measurements can be saved and reviewed against the image of the core, thus proof of every measurement is retained. Photo-manipulation can rescale images so that tree rings of different sizes can be compared directly. Skeleton plotting and tree ring measuring standardises data with respect to time, whereas this technique standardises the image size of the tree rings themselves so cores can be directly compared side-by-side. This helps by quickly identifying stretches of similar growth within cores from the same tree and from different trees, and provides the platform for visual cross-matching.

In addition to providing materials to evaluate the dendrochronological potential of this species, the motivation behind this project is to investigate the influence of hydrology on growth in the Wairarapa Valley in the southeast of The North Island of New Zealand. This area has a particular sensitivity to climate variation and the Southern Pacific Climate Oscillation (Watts, 2005). A complete tree ring network should help develop a fundamental understanding of the plant-water relationship and how river and groundwater management, including adjacent groundwater abstraction is influencing this riparian forest species.

The challenges posed by difficult wood morphology

The wood samples varied greatly, such as tree ring visibility and wood density. Wood texture affected the quality of preparation and hence the difficulty of identifying the ring borders and counting the tree rings. The species displays lobate growth, particularly with larger specimens which often have stout buttresses but lobate growth is present to some extent in most trees in all size classes. This growth habit poses problems for cross-matching because locally absent (missing) rings can often occur in one or more cores per tree or arcs of cross-sections. The corollary is that in other parts of a cross-section the rings are enlarged which makes microscope based comparison harder because the rings have such large size differences. Identifying the interannual variability can be difficult when wood samples have either very strongly or weakly growing regions.

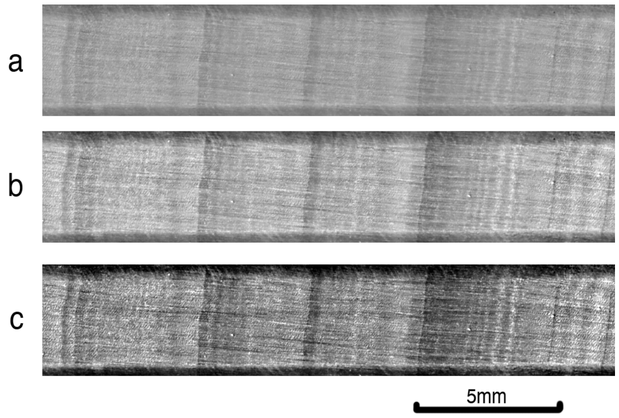

Figure 1. Faint ring borders with multiple density fluctuations and false rings. Adjusting the original scan (a) and enhancing the contrast and brightness (b) and 'blue channel only' (c) greatly improves visibility.

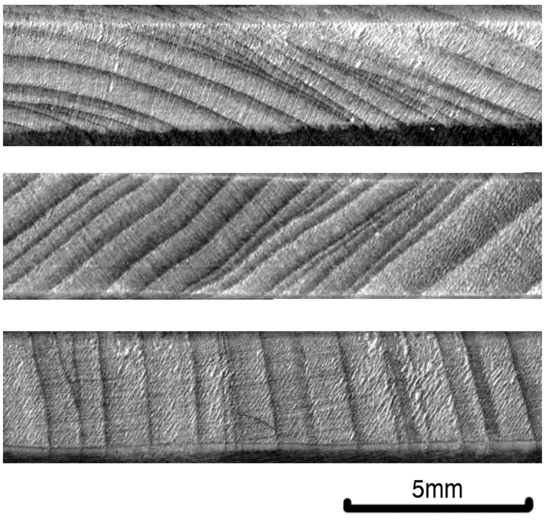

Figure 2. Examples of wedged and locally absent rings.

A further complication has been caused by false rings (see figure 1). These intra-annual structures were frequently encountered and can appear quite similar to normal ring borders (with regard to colour, morphology and size) but generally they were less well defined and the 'early-wood' between the false ring and the annual ring was comparatively very small. False rings tended to be less than 600 µm, occurring early in the growth season (possibly frost influenced) or at the end, when there could be a series (3 or more) of these anomalies. Occasionally, during cross-matching a faint ring which appeared similar to examples of false rings was, because of the context of the surrounding data, identified as an annual ring border. Conversely, extremely narrow (<600 µm) ring widths can be annual growth depending on the context. For example a series of small rings can occur under conditions of extreme competition, and across sections of lobate growth where rings are wedging (figure 2) and/or narrow but not appressed as where rings are locally absent. Narrow rings can also occur individually within a series of much larger rings and may represent a poor growth year.

Thus there seems to be no simple or fixed rules for determining whether an apparent tree ring is an annual ring border or not, and so all rings must be considered individually and within their chronological context, both within the tree and the sample site. These digital methods: using image files that allow repeated changes to counting without affecting the quality of the image; saving measurement tracks for review and the viewing of cores, side by side and of the same scale, really support the detailed and painstaking task of cross-matching.

Methodology

Core preparation

The cores were dried between absorbant kitchen-paper until thoroughly air-dry then packed for postage from New Zealand to Germany. The cores were glued to wooden mounts ready for the surface to be prepared by cutting or microtome. Several techniques have been tried but most often a WSL sledge microtome was used. Using a knife blade also provided a clean exposure but generally wasted more wood. After cutting, chalk dust was used to increase the contrast before scanning.

Scanning cores and file preparation

After preparation, the cores were scanned tree-by-tree using an Epsom Expression 10000 XL flatbed scanner with at least a resolution of 1200 dpi. Adobe Photoshop^{TM} (Adobe, 2005) was used to crop the files and the original image layer locked to prevent further changes. All markings, e.g. counting, decades or skeleton plots, were made in a new layer in the file and not on the original image itself. Separate copies of the images were kept for the different purposes, i.e. the files that would be measured were not altered from the original dimensions and the files that were used for the scaling plots were not measured.

Photoshop^{TM} offers several useful ways to adjust the image to be able to see faint structures (see fig 1.). The most useful of these has been to simply view the blue channel, meaning the blue frequencies in the image are shown in monochrome. This shows tree ring borders much more clearly and it is easy to switch between full colour and blue channel without making a change to the image. Other tools adjust the image itself and were only applied to copies of the original image saved as overlying layers. The most useful tools are found in the IMAGE tab, then ADJUSTMENTS. Changing the LEVELS, CHANNEL MIXER and BRIGHTNESS/CONTRAST can improve areas where tree rings are faint or ambiguous (see fig.1).

Counting and skeleton plots

Using Photoshop^{TM} every counted ring was marked below with a dot, decades were marked with two overlapping dots and one above using the traditional notation (1 dots for decades, 2 for 50 years and 3 for centuries). Skeleton plots (adapted from Schweingruber *et al.*, 1990) were marked in the space between cores against a white background to be more visible. Particularly large and small rings were identified by comparison to the 2 rings either side, and graded with either 3 dots for most extreme, 2 for strongly different and 1 dot for mild differences, either above or below a line to show relative magnitude. In a similar fashion skeleton plot data was recorded on paper.

Preparing files for measuring

The software Lignovision™ (Rinn, 2006) was used to measure the images. Lignovision™ supports jepg or bitmap formats but not file formats with layers so copies of each core were saved as jpeg files. Each core scan was cut into 2 or more overlapping sections. This was to provide multiple measurements of some of the rings and to reduce the size of file the computer had to handle. There is also the benefit when measuring because although measuring was conducted in the magnified window, the image is also shown in a navigation window and it was helpful to have the entire image large enough to see enough detail to help with orientation and perpendicularity while working on the magnified section.

Measuring and data treatment

Tree rings were measured using the continuous line function, i.e. clicking at each ring border and manually judging the most appropriate path across the early wood. The magnifier window was always used, most often at 3 times magnification but less if a structure appeared better defined at lower magnification. The measurement tracks and the tree ring widths were saved and the ring widths from each image section were checked and the data were saved for each complete core, and then collectively for each tree using TSAP™ (Rinn, 2005).

Scaling plot file preparation

Scaling plot files were prepared by having all the cores of a single tree as different layers in the same image file. This allows the TRANSFORM function to be conducted on each core individually and all the cores can be compared side by side on the same scale. Data of regions of cores showing strong similarities can be plotted on the paper skeleton plot of the tree's cores. Commonly the cores showed several phases or waves of larger and smaller growth rings and these can occur such that there is wide growth on one core and much less on another others. Repeatedly re-scaling the images allows for direct comparison and avoids the discomfort of extended microscope use, particularly the eyestrain from constantly switching between microscope, computer monitor and graph paper.

The favoured shorthand name for this technique is *ghost plotting* because it shows the presence of similarity in the bones of the skeleton plots without the fully resolved annual structure (see figure 3).

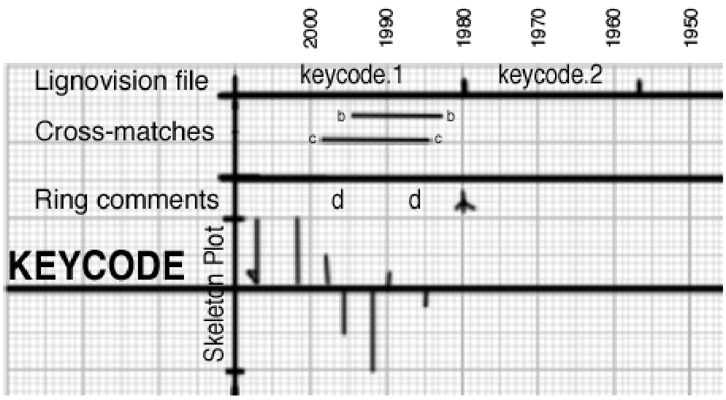

Figure 3. Example of how the data can arranged. 'Lignovision file' refers to the overlapping sub-sections of each core. 'Cross-matching' shows which regions of this core that strongly visually cross-match to regions of other cores. 'Ring Comments' would include density anomalies and missing rings etc. 'Keycode' is the core's reference code and here there is space for the skeleton plot. All cores of a tree are plotted on a single sheet of paper.

Cross-matching

The approach is incremental and acknowledges that it is practically impossible to ascribe the correct year to the tree rings in the first instance. In most cases it was possible to cross-match the pattern of tree ring growth using a series of pointer years (often groups) and directly compare each tree ring to the others in the tree until missing rings or false rings are identified. These changes are noted on the paper plot and then new versions of the images are made reflecting changes to the dating. Subsequent measurement adjustments are made and updated file versions are saved. Thus the ring width measurements are iteratively cross-matched and the data ready for analysis.

Although somewhat slower than other methods, for species that are new to dendrochronology and are proving challenging because of similar morphological features, this method's robust and practical approach to visual cross-matching could be helpful. Comparing these several representations of the cores, i.e. the scans and ghost plot files, the measurements, measurement tracks and paper skeleton and ghost plots, are very useful for managing the problems posed by the wood morphology in this species, for reducing human error as much as possible and most importantly provides a strong framework for identifying and rectifying discrepancies in the data.

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Rock spiraea (*Petrophytum caespitosum*) from the Grand Canyon – habitat and growth rings

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Introduction

Shrubs, dwarf shrubs and herbs have a large potential for dendrochronological research in cold and arid regions, where trees are not the dominant form of vegetation cover. The presence of annual growth rings in plants in these environments is significant for climatic, ecological and geomorphologic applications in cliff-face, alpine and other "extra-arboreal" regions of study. Many studies on the analysis of dwarf-shrub data have been yielded from the Arctic and high mountain environments. *Salicaceae* collected north of the Polar Circle are widely used in various studies (Woodcock & Bardley 1994, Zaltan & Gajewski 2006, Owczarek 2009), although the analysis of their anatomy is very difficult due to several factors, such as very narrow growth rings (0.001 – 0.1 mm), common discountinuous rings, missing rings and scars connected with animal grazing. The effect of periglacial processes (e.g. debris flows, creep) on the formation of growth rings as measured by tension wood analysis and identification of injuries in small dwarf shrubs (*Salix polaris* (Wahlenb.) and *Salix reticulata* (L.)), have been investigated only in the Svalbard archipelago (Owczarek 2010). Analyses of dwarf shrubs in the high mountain areas in USA have been carried out on the eastern side of the Sierra Nevada range in California. The growth form of plants occupying rock glaciers and high elevation talus/scree slopes on the arid eastern slope of this range is often a low shrub or cushion plant form (Major & Taylor 1988). Several species, e.g. *Linanthus pungens* (Torr.), sampled in this region for dendrochronological potential have been found to be long lived (up to 150 years) and to have climatically sensitive, cross-dateable annual growth rings in their persistent woody taproot (Franklin, unpublished data). East of the Sierra Nevada range, on the Colorado Plateau, the small prostrate dwarf shrub *Petrophytum caespitosum* (Nutt.) can be found. It inhabits the desert scrub community found on the upper walls of the Grand Canyon of the Colorado River. The aim of this paper is to present the habitat, ecology and wood anatomy of this shrub.

Study area

Samples of *Petrophytum caespitosum* (Nutt.) were collected on the northern edge of the Grand Canyon (the Colorado Plateau, Arizona) in the Kaibab National Forest (Fig. 1, Fig. 2) between 2,100 and 2,250 m a.s.l. The Colorado Plateau is a region of the mountainous western United States characterized by reddish layers of alternating sandstone, limestone, shale and siltstone laid down by transgressing and regressing seas during the Paleozoic Era (Crampton 1985). These layers are exposed most obviously in the walls of the Grand Canyon of the Colorado River in northern Arizona. The depth of the Grand Canyon can reach almost 2 km.

Because of the vast vertical distance covered by the canyon walls, the vegetation of the Grand Canyon falls into several different biotic communities that are influenced not only by elevation but by climate, geomorphology and geology. Immediately adjacent to the Colorado River a riparian community of willow (*Salix spp.*) exists. Above the riparian corridor, a community of desertscrub thrives with species similar to many western US deserts such as creosote (*Larrea tridentate*), rabbitbrush (*Chrysothamnus spp.*) and big sagebrush (*Artemesia spp.*). Above the desertscrub community the Pinyon-Juniper woodland extends up to approximately 1,900 m a.s.l..

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From 2,000 – 2,500 m a.s.l. Ponderosa Pine is found along with some species of oak, locust and mahogany (Fig. 2). At the upper reaches of the northern rim of the canyon (2,500 m.a.s.l.), spruce, Douglas-Fir and White Fir and Aspen can be found (McDougall 1947).

Annual rainfall for the Colorado Plateau has a bimodal pattern with peaks in rainfall in late summer (August) and late winter. The driest months occur in early summer (May/June) (Mock 1996, Spence 2001).

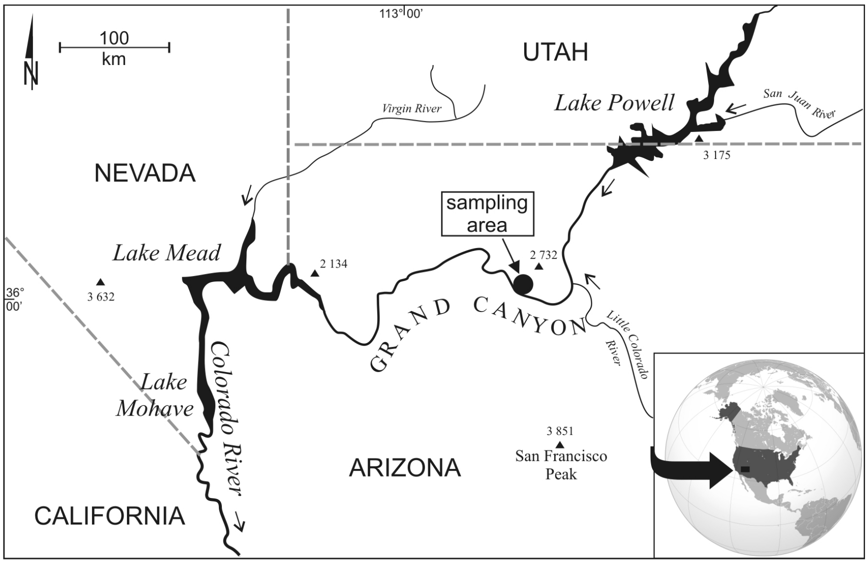

Figure 1: Location of the study area.

Figure 2: Upper part of the North Rim (Kaibab Plateau) with the sampling area on the elevation 2,200 m a.s.l. In the vicinity are visible Ponderosa Pine trees.

Methods

The samples of *P. caespitosum* were collected in May 2009. Complete individuals of *P. caespitosum,* including their root and branch systems, were collected and each individual was documented by digital images. The samples were sectioned with a GSL 1 sledge microtome, with 15 – 20 µm cross-sections taken from 2 to 4 different locations along the length of each individual. Microtome sections were prepared from the whole diameter of selected segments. The samples were drying after staining with 1% solutions of Safranin and Astrablue and dehydration. The microscopic observations were carried out using a light microscope with objective magnifications 10, 20 and 40. Digital images of the micro-sections were taken for tree-ring analysis and measurements. Wood anatomical structures such as growth ring width were measured along two to three radii using OSM 3.65 and PAST4 software.

Plant characteristics

General description

Petrophytum caespitosum (Nutt.) is a dwarf shrub commonly known as rock spiraea, rockmat or Rocky Mountain rockmat, and belongs to the family *Rosaceae*. The species grows elsewhere on limestone and igneous outcrops from desert scrub to the subalpine zone (1,700–3,100 m a.s.l), typically on the sunny edges of rock cliffs in south-western United States and northern Mexico. An isolated occurrence is also known in Washington and northwestern Oregon (northwestern US) (Hitchcock et al. 1961, Sterlin 1966, Heil & Kane 2005). The plant is common on the upper regions of the Grand Canyon walls. This part of the Grand Canyon is formed from the Kaibab limestone. Often the plant hangs downwards from the rock wall and forms "hanging gardens" (Fig. 3A) held in place by stout roots growing in wet rock cracks. This growth form is associated with the presence of water in bedding planes within the rock strata (Welsh 1989). The plant occurs as mats on the edges of rock surface as well (Fig. 3B). The lance-shaped leaves, 8-10 mm long, are grayish green and form rosettes. The stems and branch system are 1 – 3 cm in diameter and grow in horizontally spreading mats (Fig. 4AB). This prostrate shrub grows 10 – 20 cm high (without the flower spike). Mats at the research site were found to reach 1.3 m in diameter. The whitish flowers form small spike-like clusters located on a single upright stem approximately 2-3 cm tall (Fig. 4A).

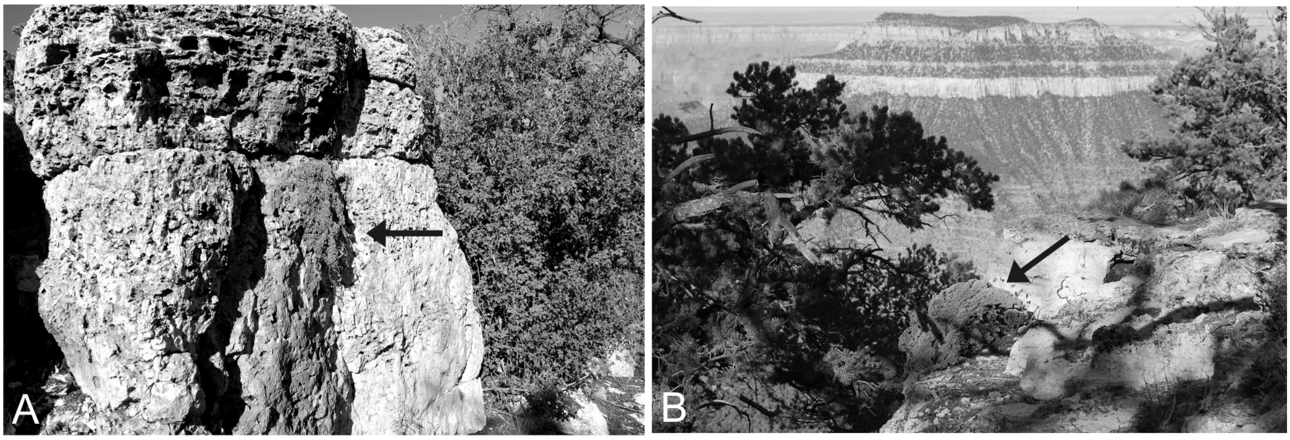

Figure 3: P. caespitosum attached to cracks in the upper part of the Kaibab limestone formation. (A) – typical growth form - "hanging gardens", (B) – the plant often forms dense mat on the cliff edge.

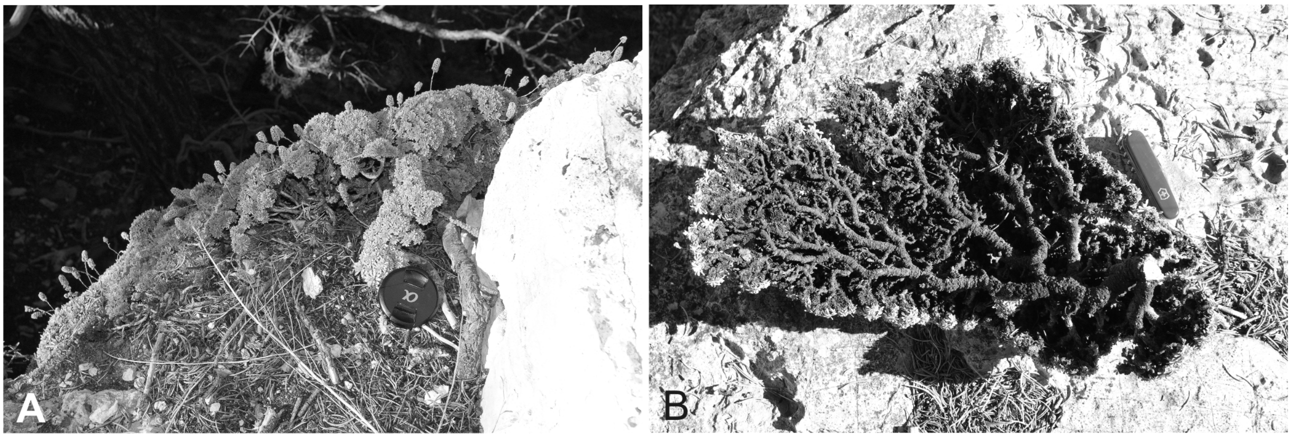

Figure 4: The individual of P. caespitosum. (A) – the stem 2.6 cm in diameter, visible small flowers on a single upright stems, (B) – the branch system.

Wood anatomy

The microscopic analysis of the samples collected indicates that this species has clear visible growth rings which range from relatively wide, 0.3 mm in width, to extremely narrow rings less than 0.1 mm in width (Fig. 5AB). Discontinuous rings are very common in this species (Fig. 5B). The border between annual rings is marked by one row of radially flattened thick-walled fibres (Fig. 5C). This species is diffuse to semi-ring porous. The size of vessels is differential with diameters from 30-50 µm (near pith) to 80-150 µm (Fig. 5A). Wide rays composed of relatively large cells are typical for similar plant species growing in rock crevices (Schweingruber & Poschold 2005). The rays often reach 500 µm in width and diameters of cells vary from 10 to 50 µm (Fig. 5C).

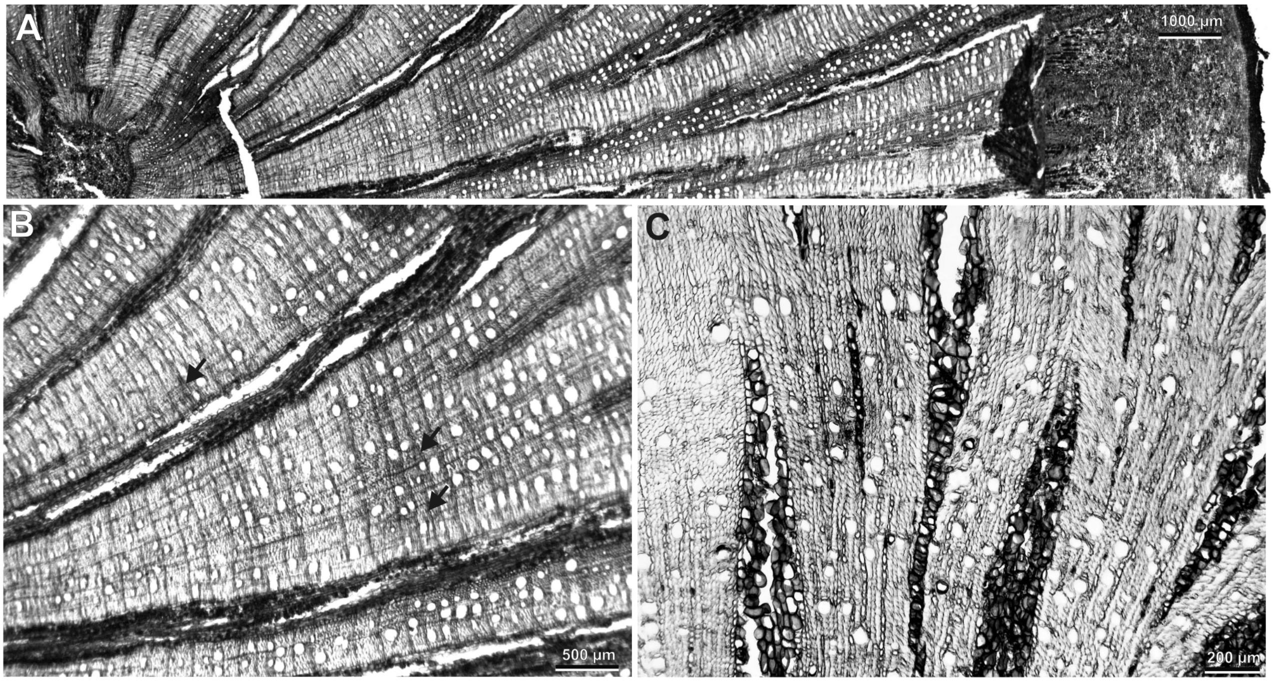

Figure 5: Examples of wood anatomy features of Petrophytum caespitosum (A) cross-section of the individual, note large bark and system of wide rays, (B) growth rings, arrows indicate discontinuous rings, (C) growth rings marked by one row of thick-walled fibres, note rays composed of large cells.

Final remarks

The most important question for dendrochronological analysis is: are the growth rings in *P. caespitosum* annual in nature? Growth-ring boundaries are distinctly visible in the samples we analysed and a maximum of 86 rings were counted. Although precipitation values are low, a bimodal pattern of rainfall is noted at the Grand Canyon with peaks in precipitation during August and March. These two peaks of rainfall may cause the development of two growth rings during one year. Analysis and research on this species should be continued in the future to solve this question (as to the annual nature of growth rings in *P. Caespitosum*) because chronologies of long-lived woody shrubs from extra-arboreal regions (where trees are absent or rare). Complement the existing tree ring chronologies can also yield climatic, ecological and geomorphological information for a greater spatial extent than tree-ring chronologies alone. This species especially demontrates its excellent potential for the use in dendrogeomorphological analysis, if the determination of correct ages of *P. caespitosum* can be achieved. Rock falls are a common geomorphic phenomena on the Colorado Plateau. The establishment age of a plant enables the determination of the minimum age of rock fall events in the past, the rate of rock wall retreat and will allow potential risk areas to be identified.

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Trees reaction after windthrow recorded in tree rings of pristine *Picea abies* forest ”Parangalitsa”

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Introduction

Natural disturbances in Norway spruce (*Picea abies* Karst) forests is one of the topics that attract much attention in forest ecology studies in recent years. Among the reasons for this were several big storms in the last decades that caused wide-spread damages in high mountain forests (Lassig and Schonenberger 2000; Fischer et al. 2002; Schelhaas et al. 2003; Zielonka et al. 2009; Heurich 2009). Further more there are expectations, that climate change might increase the severity of storms thus making the topics for natural disturbances, forest resistance and resilience even more important in future (Dale et al. 2001; IPCC 2007). Yet, information about natural dynamics and disturbance regime of Central and South European high mountain Norway spruce-dominated forests is still limited (Korpel 1995; Krauchi et al. 2000; Holeksa and Cybulski 2001; Splechtna et al. 2005; Brang 2005; Svoboda and Pouska 2008; Zielonka et al. 2009). An option to fill-in some of the knowledge gaps on disturbance regimes of spruce-dominated forests in South-Eastern Europe is to conduct studies in the few remaining pristine forests in the Balkan Mountains and in the Carpathians. Yet, such studies often face numerous challenges, and one of the most important is the lack of written records for past disturbances and forest development. Therefore reconstructive methods that allow acquisition of data with yearly or at least decadal resolution are needed. Relatively affordable and popular are those based on the analysis of tree rings. They allow a non-destructive way of data acquisition with yearly resolution, which is a very good proxy for the past growth of single trees (Schweingruber 1996). Therefore tree ring analysis has been one of the main tools to reconstruct past disturbance history and dynamics of forests (Rubino and McCarthy 2004). Another problem that exists in tree-ring studies of disturbances is the definition of trees' reaction after the disturbances. Most studies have used as a clue abrupt increase of tree ring width (i.e. a release), which is considered a consequence from reduced competition and more available growth resources for the survival trees (Lorimer 1985; Veblen et al. 1994; Cherubini et al. 1996; Kulakowski et al. 2003; Black and Abrams 2004; Splechna et al. 2005; Zielonka et al. 2009). Yet, there have been difficulties in defining the criteria to detect which increases of tree-ring width can be considered as releases and many calculation methods have been applied (for a discussion see Rubino and McCarthy 2004). One of the approaches developed to cope with this problem (i.e. the “boundary release criteria”, Black and Abrams, 2004) accounts for differences in the possible growth change dependent on the species and social status of a studied tree. Yet, it is mostly applicable for large data sets which often researchers do not have for their region. Furthermore the method has complicated calculation procedure, which hinders the use with smaller datasets derived from spatially-explicit data-collection strategies that provide low number of cores from a small region, but carrying important disturbance signals.

Here we present results from tree-ring study of the disturbance history in Parangalitsa forest reserve in Bulgaria. It has been declared a natural reserve in 1933, but even before that was considered as a protected forest and human activities were limited to hunting of local governors and pasturing on the higher grass-lands above the forest. Timber harvesting on large scale was not allowed and the lack of roads additionally hindered any possible attempts. Therefore the forest presents the chance of studying natural dynamics for at least the age of the dominant cohorts

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(above 200 years). To perform our study we firstly developed maps of spatially definable forest patches and recent disturbance based on two sets of aerial photographs (in 1966 and 1997) (Panayotov et al. 2010). Then we collected tree ring samples from survival trees on the borders and within disturbance patches with different scales.

The main objective of our research was to study the reaction of trees after disturbances with different scales and severity. We hypothesized that although the general pattern would not be too different from other known examples, species and social-status specific reactions between light-demanding *Pinus* and shade tolerant *Picea* and *Abies* trees can be found. We also asked our selves whether we would be able to find differences dependent on the scale of disturbances (e.g. gaps or medium and large-scale windthrows)?

Material and methods

Study site

Our study site is situated in the upper parts of Bistritsa valley in the Rila Mountains in Southwestern Bulgaria (Fig.1). The study forest (250 ha) is situated between 1450 and 1950 m a.s.l in "Parangalitsa" reserve, which is one of the first strict forest reserves on the Balkan Peninsula. In was declared in 1933 and in 1977 it was included in the "Man and biosphere" list of UNESCO. The forests are dominated by Norway spruce (*Picea abies* Karst). At lower altitudes (e.g. up to about 1650 m a.s.l.) there is participation of up to 70% of Silver fir (*Abies alba* Mill) and up to 40% of European beech (*Fagus sylvatica* L.), while at the treeline belt there is limited participation of up to 20% of the Balkan endemic species Macedonian pine (*Pinus peuce* Griseb.). In many of the forest patches with heterogeneous structure there is participation of Scots pine (*Pinus sylvestris* L.) in the oldest cohort (up to 40 %).

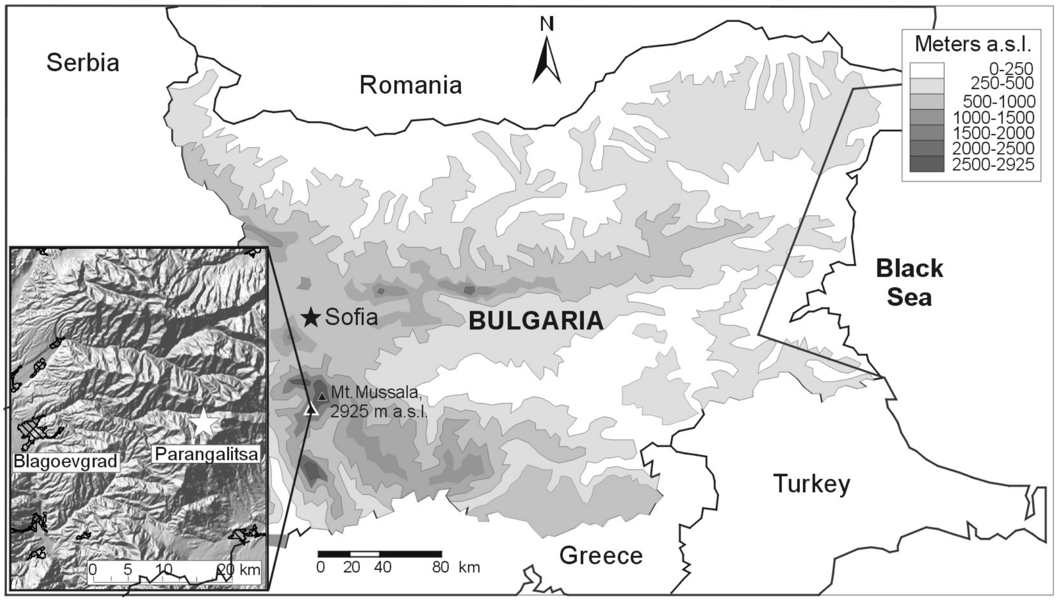

Figure 1: Study site position

The climate in the reserve is mountainous with influence from both Atlantic and Mediterranean cyclones. The average annual temperature at 1400 m a.s.l. is 4.9°C. It ranges from a mean monthly temperature of -3.7°C in January to +14.5°C in July. The annual precipitation amounts to 933 mm, with a maximum in late spring and early summer (Raev et al. 1986). Soils are dominantly brown-forest spoils (Dystric Cambisols) and dark-mountain soils (Umbric Cambisols). The brown soils are found mostly under mixed *Picea-Abies-Fagus* forests from 1500 to 1650 m a.s.l., while the dark mountain soils are found under the pure *Picea* and mixed *Picea-Pinus* forests (Georgiev 1981).

Data collection and analysis

Based on interpretation of aerial photographs from 1966 and 1997 (Panayotov et al. 2010) and historical records we selected several sub-regions with windthrows within the 250 ha forest: A) a border zone of a famous windthrow that happened in 1962 and caused complete blowdown on a territory of more than 20 ha; B) a zone occupied by old forest (150-230 yrs) with active gap processes between 1966 and 1997; and C) even-aged patches, which in unmanaged forests usually originate after canopy-removal disturbances (Oliver 1981). From the border zone of the catastrophic windthrow (study region A) we collected cores at breast height from 66 survival trees. Survival trees on the territory of the blowdown were also sampled. From the edges of the recently formed gaps (study region B) we collected cores from 33 trees. From the borders of the even-aged patches we collected 24 cores from biggest and presumably oldest trees that were expected to be older than the majority of trees within the patches and therefore contain clues for a possible disturbance event.

Sample processing

Tree ring samples were air-dried, mounted on wooden holders, and sanded with successively finer grades of sandpaper. Annual rings were recorded with semi-automatic video equipment at the dendrochronology laboratory of the Institute of Forest Growth (IWW) in Freiburg with precision of up to 0.01 mm. Measurement and cross-dating was performed with the Woodscan software (IWW) following standard procedures (Stokes and Smiley 1968).

To qualify trees' reactions after the disturbance events we calculated the change of tree ring width relative to the average of the previous ten tree rings. We subdivided the trees according to their reactions in 5 release classes (e.g. tree ring width relative to the mean of the previous 10 years from 1)140 to 160%; 2)160-180%; 3)180-200%; 4) 200-220% and 5) >220%) and 5 decrease (suppression) classes (e.g. e.g. tree ring width relative to the mean of the previous 10 years from 1) 0 to 30%; 2) 30 to 40%) 3) 40 to 50%; 4)50 to 60%; and 6) 60 to 70%. To verify if there was a time lag of reactions, the growth changes after the 1962 windthrow were analyzed in two periods – the first 5 years after the event (e.g. 1963-1968) and 5 to 10 years after the event (e.g. 1969-1973). We considered as releases or decreases only cases, when the reaction was sustained for at least 3 to 5 years.

Results and discussion

Almost half (45%) of the sampled 66 trees at the borders and within the 1962 windthrow patches displayed radial growth decreases (i.e. suppression) in the first 5 years after the disturbance (fig. 2). Most of the suppressions were between 70 and 50% relative to the average of the previous ten years. During the first five year period releases were observed in 150% of the trees. This type of reaction was predominant in the period from 5 to 10 years after the disturbance. Then a third of the trees (32%) displayed releases. While the majority of tree-ring width releases were between 160 and 200% (52%), about 25% of the trees increased their tree ring width to more than 200%.

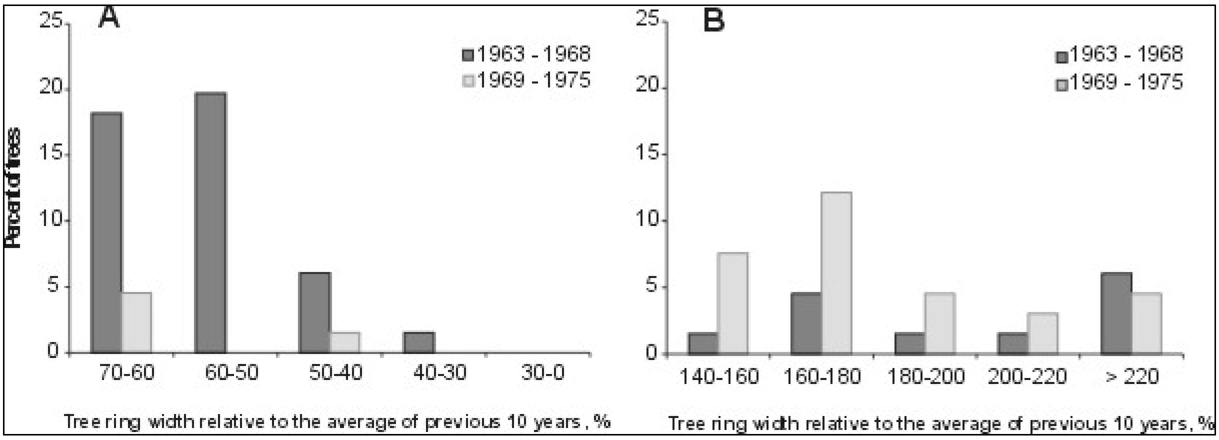

Figure 2: Tree ring width suppressions (A) and releases (B) after the windthrow in 1962.

We could distinguish three main groups of trees according to their pattern of reaction after the 1962 windthrow. The highest number (30%) displayed only a sudden growth decrease and did not release according to our criteria in the following 10-year period (fig. 3A). In most cases such trees recovered steadily, but without sudden tree ring width changes in their growth. Trees that only released (fig. 3B) were slightly more (20%) than those which displayed an abrupt growth suppression followed by a release (12%) (fig. 3C). Strongest reactions were found in tree ring samples from *Abies alba* and *Picea abies* from the lower altitudes of the affected zones. *Pinus* trees (*P. sylvestris* and *P. peuce*) either did not display a growth suppression or release within the specified percentage classes, or reacted by small growth changes.

The predominance of suppression reactions in the first five years after the 1962 storm could be explained in several ways. Many of the trees suffered crown damages, which still can be observed on site. In such cases the tree suddenly looses a substantial part of the photosynthetic green mass system and thus accumulation of the necessary for wood production carbohydrates is seriously decreased (Schweingruber 1996). This causes production of either incomplete tree rings, which may appear as locally missing tree rings, or production of very narrow tree rings (Panayotov 2005). Even if the crown is not injured the shaking of the stem during a very strong storm can cause damages to the root system and especially to the fine roots (Stokes 1999) which are responsible for the major part of the intake functions of the roots (Marchand et al. 1986). On its side this can also cause growth stress and result in production of narrower tree rings.

In contrast to the reaction of trees after the 1962 windthrow, the 33 trees at the edges of recently formed gaps displayed mostly radial growth increases (i.e. releases). This was found in 88% of the cores (Fig. 4). The percentage of trees with radial increase of more than 200% (48%) was also higher than that of the survival trees from the 1962 windthrow. Abrupt growth suppressions were found in smaller number of trees (24 %).

Probably the storms that caused uprooting of one or several trees and thus the formation of gaps were less severe than those causing complete blowdown over larger territories. Thus the trees at the border of the newly formed gaps might have not suffered crown, root or other damages. In opposite, they acquired access to more space for crown growth and more light after the disappearance of some of the direct competitors. More over that some of the survival trees on the borders of the gaps were co-dominants at the time of the gap formation and thus received the chance to become dominant trees. Such changes in the social status and resource availability of the trees could explain the release reactions in the tree ring cores.

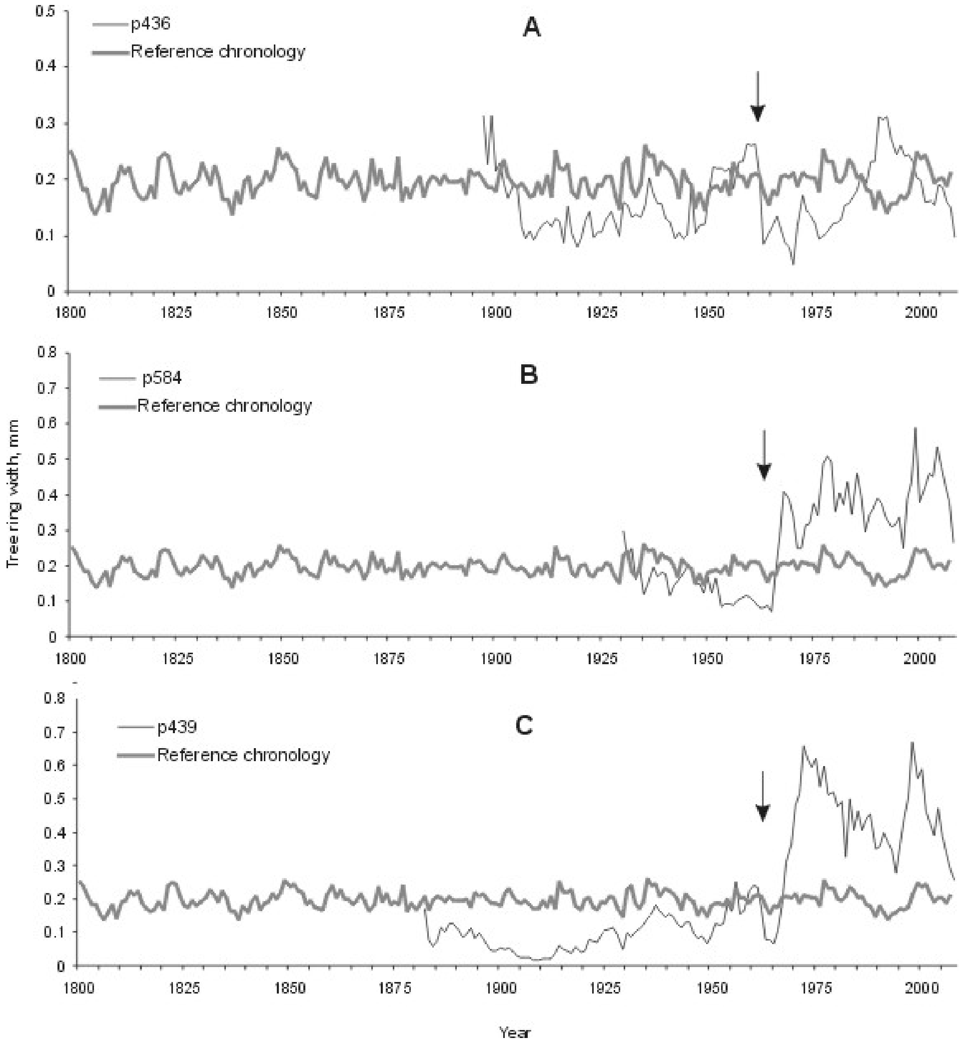

Figure 3: Pattern of tree ring width change after the 1962 windthrow: A: abrupt suppression; B: abrupt release; C: abrupt suppression followed by a release. Arrows indicate the year of disturbance.

The shade tolerant *Abies* and *Picea* trees reacted by higher changes in the tree ring width than the light demanding *Pinus* trees both in the cases of catastrophic windthrow and gap formation (fig. 3). We consider that the reasons are related to the social status trees and genetic features of the trees. In our case the *Pinus* trees were dominant trees within the canopy. Thus their crowns were accustomed to more light and could not benefit much from the sudden reduction of competition for light. Additionally both *Pinus sylvestris* and *Pinus peuce* form small crowns situated at the top of the canopy when there is higher competition. Thus their crowns could not benefit from the sudden occurrence of more light at the lower and middle layers of the canopy and this explains the smaller changes of ring width. In opposite *Picea abies* and *Abies alba* trees generally from long crowns covering a large part of the stem. Their lower crown parts remain in shadow and contribute less for the general carbohydrates production. In cases of gap opening the lower parts of the crowns receive more light and may increase the photosynthesis rates and carbohydrates production. Thus these species benefit much more from the increased side light. Additionally *Picea* and *Abies* survive for long periods under the shadow of canopy and then can benefit from the death of dominant trees. Thus if the trees were suppressed or even co-dominant at the moment of gap formation they could suddenly increase their growth both in length and radius, which is detectable as growth release.

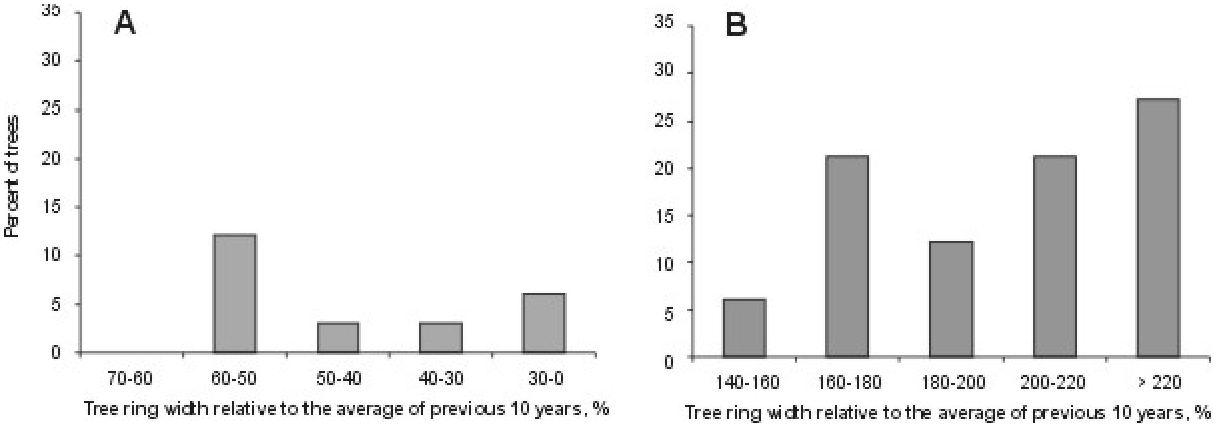

Figure 4: Tree ring width suppressions (A) and releases (B) at the border of gaps formed in the period 1966-1997.

Rather small number of trees on the borders of the two analyzed even-aged forest patches reacted after the disturbances. Although most of them produced much wider tree rings (i.e. releases) some also displayed growth suppressions (fig. 5). Yet, the small number of reacting trees does not allow a clear distinction of the predominant response type after the disturbance event that destroyed most of the trees in these regions. A possible problem in defining the response of trees is the rather long time lag (more than 100 years) after the events and the high chances that some of the surviving at that time trees have already died. Yet, about 15% of the found old trees displayed sharp releases (e.g. above 200% of tree ring width increase).

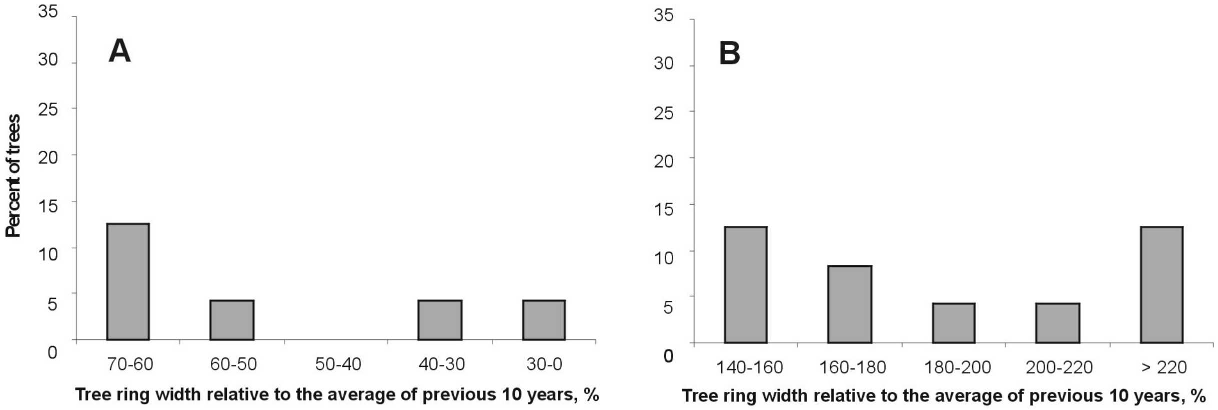

Figure 4: Tree ring width suppressions (A) and releases (B) at the border of forest patches with uniform structure formed after disturbances approx. 100 years ago.

Our findings confirm the conclusions of other studies that sudden changes of tree ring width are common after wind disturbances in coniferous forests (Lorimer 1985; Veblen et al. 1994; Cherubini et al. 1996; Kulakowski et al. 2003; Black and Abrams 2004; Splechna et al. 2005; Zielonka et al. 2009). Yet, our data demonstrates that abrupt suppressions may be the predominant type of trees' reactions immediately after severe storms and thus should not be disregarded in disturbance studies. In opposite, the decrease signals may help estimate more precisely the year of storm event when they are simultaneous and situated within a specific region. From the point of view of applying the release criteria for dating disturbances this means that a wrong estimate can be made. In many cases this would not be a problem because researchers often look for decades in which there was a disturbance. Yet, if higher precision is aimed suppression signs could also be used as a clue. One other point of interest is that if we had applied to our dataset approach, that does not take into account the exact position of trees, but detects only highly-repeated release patterns, we would miss to detect the disturbances in older periods. Because the number of surviving trees is rather small their reactions would diminish if the percentage of all reacting trees within the study forest is considered as clue for a stand replacing disturbance.

Conclusion

We found that the majority of survival trees at the border of a severe windstorm in Parangalitsa reserve experienced growth suppressions in the first 5 years after the event. Growth releases were delayed and predominant in the period from 5 to 10 years after the disturbance. In opposite survival trees at the borders of recently formed gaps displayed mostly sharp releases. Growth suppressions were high, but in low number of trees. Few survival trees at the borders of stand replacing disturbances that happened approximately 100 yrs. ago displayed clear release or suppression pattern. Yet, they could be used to date successfully the events in combination with other clues such as aerial photographs and age of clearly definable cohorts formed after the disturbances. Our results demonstrate that in retrospective disturbances studies in coniferous forests growth suppressions should not be neglected but used in combination with growth releases.

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Dendrochronological record of scree slopes activity on Ostrzyca basalt plug (South-Western Poland)

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Introduction

Geomorphological processes such as mass movements influence the environment in various ways regarding their intensity and pace as well as other factors, *e.g.*, like bedrock type or climate zone. Effects of such movements are recorded also in trees growing on unstable ground. Translocating material results in constant pressure on the stem from the upslope side, which consequently tilts the tree according to the movement direction. Changes caused by reactions of the plants to the activity of the ground can be observed in the annual increments. Trees form so-called reaction wood and exhibit eccentric growth, *i.e.* various portions of xylem are produced on the upslope and downslope parts of the stem. These differences in increment result in varying ring widths during the ground activity. Such phenomenon enables the application of dendrochronological methods for the analysis of geomorphological processes (Heinrich et al. 2007, Heinrich & Gärtner 2008, Stoffel & Perret 2006, Stoffel et al. 2005, Perret et al. 2006, Malik & Owczarek 2006, Kaczka & Morin 2006).

Scree slopes are surfaces consisting of sharp-edged rock debris formed by mechanical weathering of rock walls. Formation of scree slopes is strictly related to the rock wall as they are accomplished at its cost. Over the time the rock wall retreats and stops delivering fresh rock material, so the debris cover becomes stabilized. Scree slope activity expresses itself in two forms: delivery of new material and talus creep, i.e. gravitational transportation of the material within the slope. Talus creep, especially when debris cover is concerned, is one of the slowest mass movements. The mechanism of the process lies in the pressure put on the ground, which results in slope material being pushed and squeezed out alternatingly. As a result it is transported down the slope (Migoń 2006).

Scree slopes still remain one of the least examined land forms in the Sudety Mountains. So-far, studies (Baraniecki 1952, Synowiec & Jasińska 2002, Remisz et al. 2009) were fragmentary and did not cover the issue of their present activity. The application of dendrochronology for that purpose is rare (Malik et al. 2009).

The objective of the present study was to assess the activity of Ostrzyca scree slopes with the use of dendrochronological methods and to determine factors that control it.

Study site

Research was located on Ostrzyca (51 03' N, 15 46' E; 501 m a.s.l) in south-western Poland. The hill is the highest point of the Pogórze Kaczawskie, the foreland area of central part of the Sudety Mountains (Fig. 1). Ostrzyca is a plug whose origin is related to local volcanic activity that took place during late Tertiary block movements (Migoń et al. 2002). The hill constitutes a deeper part of volcanic neck that was exposed as a result of selective denudation (Birkenmajer 1967). It has a regular conical shape characterised by distinct concave-convex slope profiles (Fig. 1). Upper part of the hill (above 430-440 m a.s.l) is built of basalt rocks and debris, while the lower one consists of less resistant sedimentary formations, which the neck broke through.

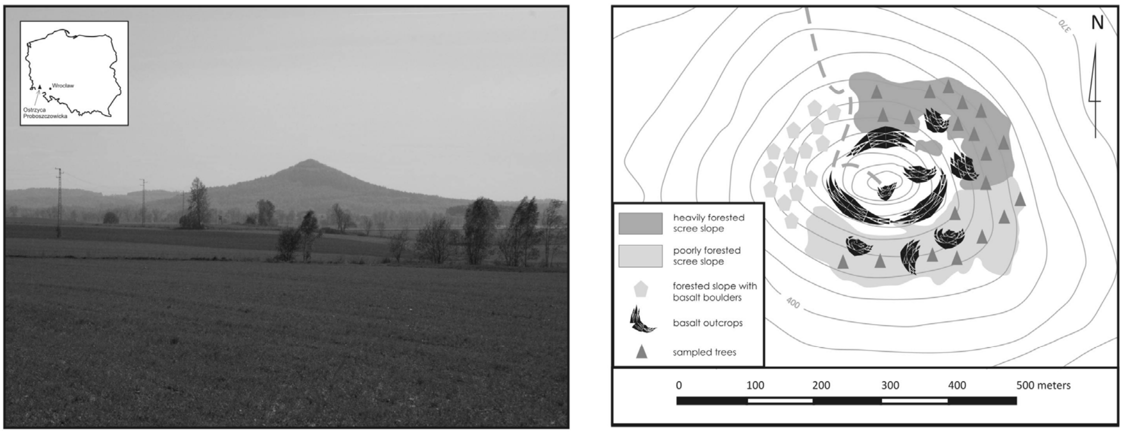

Figure 1: View on Ostrzyca and the scheme of the study site with location of sampled trees.

In 1926, Ostrzyca was recognized as a nature protection area. However, in 1944 it was converted for military purposes (construction of trenches), but in 1962 the protection status was restored. At present, “Ostrzyca Proboszczowicka” nature reserve covers 3,81 ha (Staffa 2002). As a result of the protection status the research area has remained relatively natural and has not been transformed by human activities, e.g. by establishing quarries. Thus, the original character of the area is preserved and geomorphologic forms are well-defined and distinguishable in nature.

Material and Methods

Research focused on the upper part of Ostrzyca, where disintegration of basalt outcrops lead to scree slope formation. We assessed both forms of scree slopes activity. Trees growing on the Ostrzyca slopes were examined for the presence of scars. We sampled 15 elms (*Ulmus glabra*), 3 maples (*Acer platanoides*), 1 sycamore (*Acer pseudoplatanus*) and 1 lime (*Tilia cordata*) chosen at random to detect the ground movements. We took two increment cores per tree. They represented upslope and downslope sides of the stems. For further analyses material was prepared according to the conventional procedures (Bräker 2002). We used CooRecorder and CDendro software (www.cybis.se) for tree-ring width measurements, cross-dating and chronology building.

To detect the episodes of scree slopes activity, we compared upslope and downslope chronologies of individual trees. Divergence in the course of increment’s width resulting from uneven xylem production caused by tree tilting (eccentric growth patterns) served as a diagnostic tool (Krąpiec & Margielewski 2000). We determined the beginning year and duration of the mass movements. In order to find out, if the intensive rainfall influences activity of Ostrzyca slopes, we compared the constructed tree ring chronologies with annual sum of precipitation. The climate data originated form Świerzawa meteo-station (10 km in SE direction) and covered the period 1977-2007.

Results

Out of the two forms of scree slope activity, only talus creep was observed on Ostrzyca. We did not find evidence of current delivery of new material as there were no injured trees with scars. The rock debris had round-shaped edges and usually was covered with vegetation (Fig 1, 2). Eccentric growth occurred in sampled trees.

Forest cover on Ostrzyca is relatively young, since the average age of the investigated trees was approximately 60 years. Only five sampled specimens were older than 100 years. The oldest sampled tree (elm) was 136 years old and the youngest (also elm) – only 54 years old.

Figure 2: Differences in vegetation cover between northern (left) and southern (right) slopes of Ostrzyca.

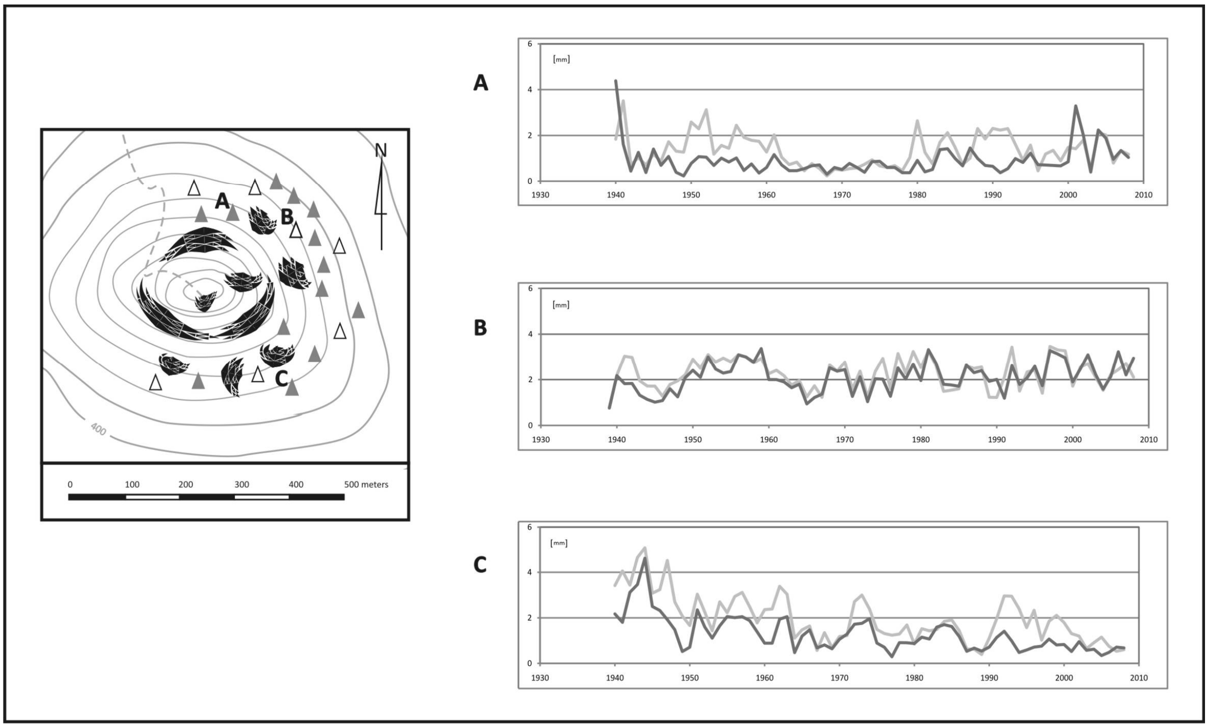

Figure 3: Spatial distribution of trees with (full triangles) or without (empty triangles) evidence of scree slopes activity and examples of chronologies representing 'active' (A, C) and 'non-active' (B) specimen (grey – upslope, black – downslope side chronologies).

Evidences of talus creep (eccentric growth) were found in thirteen trees, while in seven specimens no characteristic divergence in course of increment was observed (‘active’ and ‘non-active’ on Fig. 3 respectively). In the 20th century the slopes of Ostrzyca were very active during the years 1945-1962 and 1980/1990s (Fig. 4). The highest activity was observed in the period 1954-1960, when six to nine trees exhibited eccentric growth. Length of the individual episodes of talus creep varied from 3 to 13 years. The average duration of mass movements recorded in the constructed chronologies equalled 7,1 and 7,5 years on southern and northern slopes, respectively. No specific pattern of spatial distribution of trees indicating possible concentrated areas of talus creep was observed. Neither was it found that high rainfall coincided with periods of slope activity.

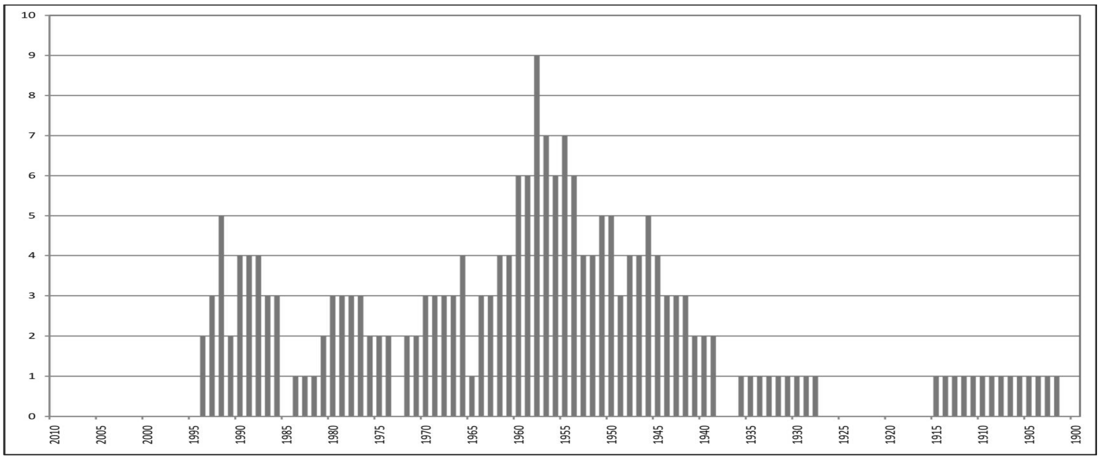

Figure 4: Temporal distribution of trees with growth eccentricity.

Discussion

The examination of living trees gave no evidences of delivery of new material to the debris cover but applied dendrochronological methods helped to detect the presence of temporary talus creep. These observations prove that scree slopes of Ostrzyca are still active geomorphological forms even nowadays. In the Kamienne Mts., Malik *et al.* (2009) found evidences of both forms of scree slopes activity. Not only fresh material deposition, but also mass movements in that area were distinct and well-defined. However, this activity seems to be the result of ongoing transformation of relatively young landslide scarps (Malik et al. 2009). In contrary, scree slopes of Ostrzyca were formed by the destructive impact of intensive physical weathering that occurred under periglacial conditions during previous glacial periods (Migoń et al. 2002). Hence, at present they are almost in a state of equilibrium as far as new material delivery is concerned (Kotarba 1976).

Intensity and occurrence of talus creep on Ostrzyca scree slopes are not related to the abundance of vegetation cover. Presence or lack of eccentric growth was found on densely forested western, northern and partly eastern slopes where rocks and debris originate from basalt outcrops and where they are intensively covered with lichens, mosses and herbal plants. Similar observations were made for the southern and eastern parts of the hill where the vegetation is rather sparse and occurs only on flat areas over rocks, in places where the slope changes its profile and at the end of debris cover.

Spatial distribution of tilted trees that exhibited eccentric growth suggests that talus creep on analysed slopes has rather local character. Narrow activity zones may be related to ridges of debris and locations where slopes become slightly steeper. However, confirmation of such a hypothesis requires further and more-detailed studies.

In contrary to observations from the Kamienne Mts. (Malik et. al 2009), no relationship was found between activity of scree slopes and annual precipitation on Ostrzyca. This disagreement may be caused by too short climate data series available to us. However, the debris covers at these sites vary regarding the shape of the material (tile-like stones in the Kamienne Mts. vs. more round/cubic on Ostrzyca). Furthermore, the role of animal trampling as a factor triggering debris cover transportation cannot be excluded. According to Govers and Poesen (1998) this phenomenon may contribute significantly to the evolution of scree slopes and should certainly not be neglected in study areas combining steep slopes and high density of wild animals. This may be partly reflected in the study area since Ostrzyca was declared as a nature reserve and hence, wild game may find refuge and good living conditions there.

Conclusions

The application of dendrochronology allowed to assess the activity of scree slopes of Ostrzyca basalt plug. Diversified spatial pattern of talus creep evidences suggest a wide-spread presence of abundant but rather narrow zones where this indiscernible type of mass movement takes place currently. We found that neither the vegetation cover nor the precipitation had any influences on the activity of examined scree slopes.

Acknowledgements

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Eccentric growth of trees as a tool for reconstruction of mass movement activity (example from the Carpathian Mountains - Central Europe)

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Introduction

Houses and other infrastructure in mountainous areas are quite frequently destroyed by mass movements, especially landslides. Therefore it is very important to study the conditions under which mass movements occur. Overall, various methods are used to study mass movement episodes such as radiocarbon dating, lichenometric dating, cosmogenic nuclide dating, uranium-series dating, Optically-Stimulated-Luminescence (OSL) dating, and dendrochronology (Lang et al., 1999). In forested areas, mass movements can be recorded by analyzing growth reactions in influenced trees: reaction wood, the occurrence of resin ducts, abrupt growth changes and the occurence of tree growth eccentricity (Baumann & Kaiser 1999, Gärtner, et al. 2003). Tree ring analysis allows dating e.g., the occurrence and course of eccentricity and thereby to indirectly date mass movement episodes. The years with episodes can be compared, for example, with the intensity of precipitation recorded at meteorological stations. Such studies can determine the threshold amount of precipitation above which mass movements occur on individual slopes.

Studying tree stem eccentricity was previously used to reconstruct mass movement activity (Braam et al. 1987), and in additional an eccentricity index was defined by Casteller et al. (2007) for reconstructing avalanches. Method developed by Casteller et al. (2007) was based on a morphometric comparison between, respectively, the measurements of both the maximum and minimum dimension of the trunk (external feature) and the annual ring width in a parallel and perpendicular direction with respect to the slope (internal feature).

In this paper authors propose an alternative approach and method for calculating the tree-ring eccentricity index. The application of the newly developed formula for the index was described. The index was also used to compare eccentricity in trees growing on slopes where mass movements occurred and in trees growing close to the streambank of a mountain stream where erosion had occurred.

The tree-ring eccentricity index as a tool for recognising mass movement

The aim of the study was to find the most useful and accurate method for the spatial and temporal reconstruction of mass movement activity. The growth pattern of spruce trees (*Picea abies*) was studied on a relatively stable slope with a smooth surface (reference site) and on a slope with distinct morphological symptoms of mass movements (study sites). The reference site was used to compare annual tree-ring records from trees growing under and without the impact of landsliding.

It was observed that spruce trees growing on the study sites are tilted and have deformed stems. Trees growing on the upper part of the studied slope are tilted upslope. Trees on the lower part, near the stream channel, tend to tilt downslope (Fig. 1).

We sampled 52 trees: increment cores were collected on the basis of surface gradient. Cores were taken from parts of trunks deformed by mass movements. Cores were taken from trees growing in different locations: on headscarps, flattenings and toes. One core was taken through each tree trunk. Samples were taken parallel to slope gradient. We compared the width of rings formed by individual trees on the upslope and downslope sides of trunks and calculated tree ring eccentricity upslope or downslope. To compare individual trees with one another, the eccentricity index was applied. The eccentricity index was calculated according to the following formulae:

$$E\ [\mathrm{mm}] = U - D; \qquad [1]$$

if $E\ [\mathrm{mm}] > 0$:	upslope tree-ring eccentricity	$Ei\ [\%] = (E / D) \times 100\%$	> 0;	[2a]
if $E\ [\mathrm{mm}] = 0$:	no tree-ring eccentricity;	$Ei\ [\%] = E\ [\mathrm{mm}]$	$= 0$;	[2b]
if $E\ [\mathrm{mm}] < 0$:	downslope tree-ring eccentricity	$Ei\ [\%] = (E / U) \times 100\%$	< 0;	[2c]

where:
U – upslope tree-ring width [mm];
D – downslope tree-ring width [mm];
E – eccentricity of tree ring [mm];
Ei – eccentricity index of tree ring [%].

In order to compare data from different trees, the raw data in mm was converted into percentages. An example of the eccentricity index calculation from raw data (transformation of graphs) is presented in figure 2. Figure 5 presents the differences between the eccentricity index calculated for samples taken from different geomorphological locations.

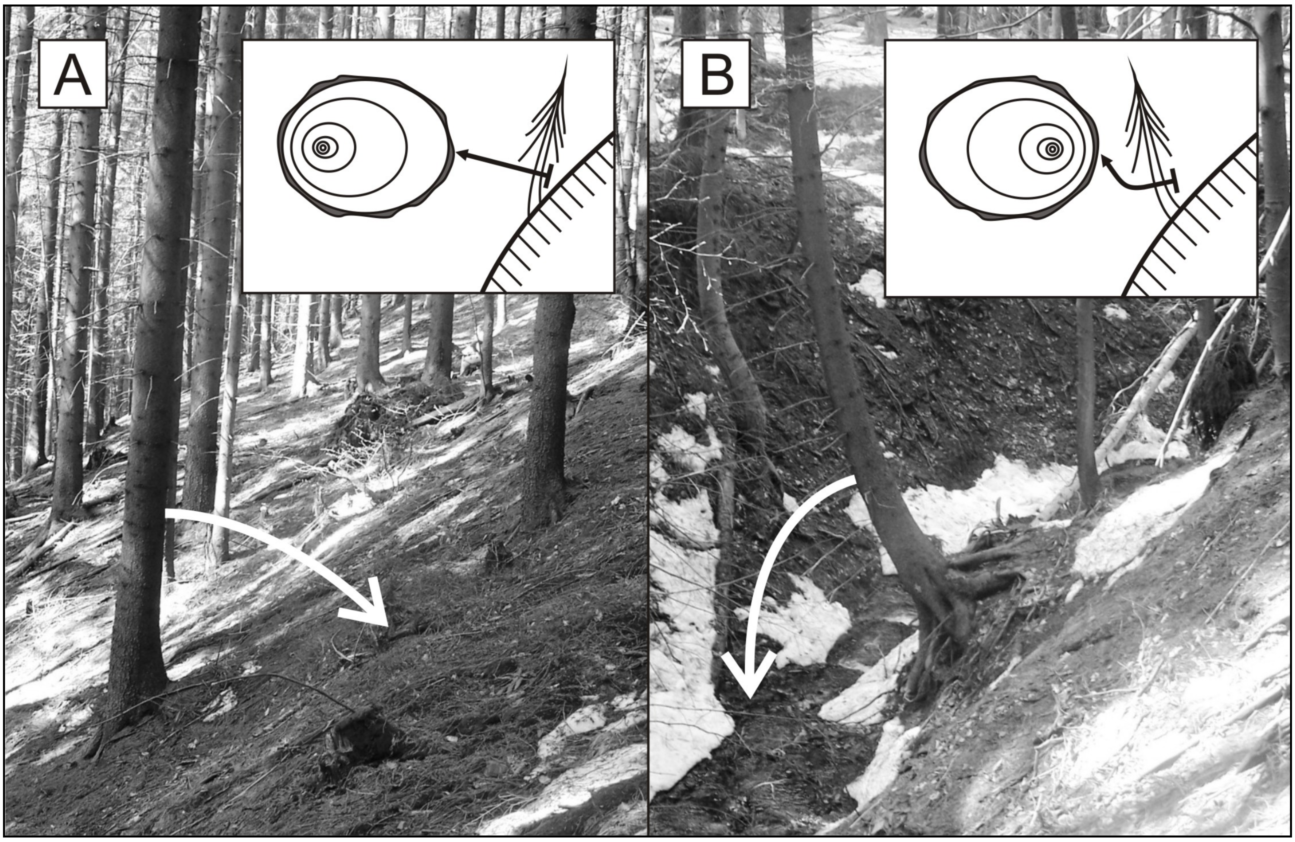

Figure 1: Trees tilted A – upslope, producing upslope tree-ring eccentricity, upper part of the study site Kp 2, B – downslope, producing downslope tree-ring eccentricity, lowest, near-channel zone of the study site Kp 2.

Results from the Skalka study area

The study was carried out in the Moravskoslezské Beskidy mountain range in the Western Outer Carpathians. The study site lay on a large landslide (650 m long, 250 m wide) filling up the valley head of the Skalka stream (Czech Republic, Fig. 3A-B). The bedrock of the study area is composed of sedimentary flysch, prone to mass movement including landsliding.

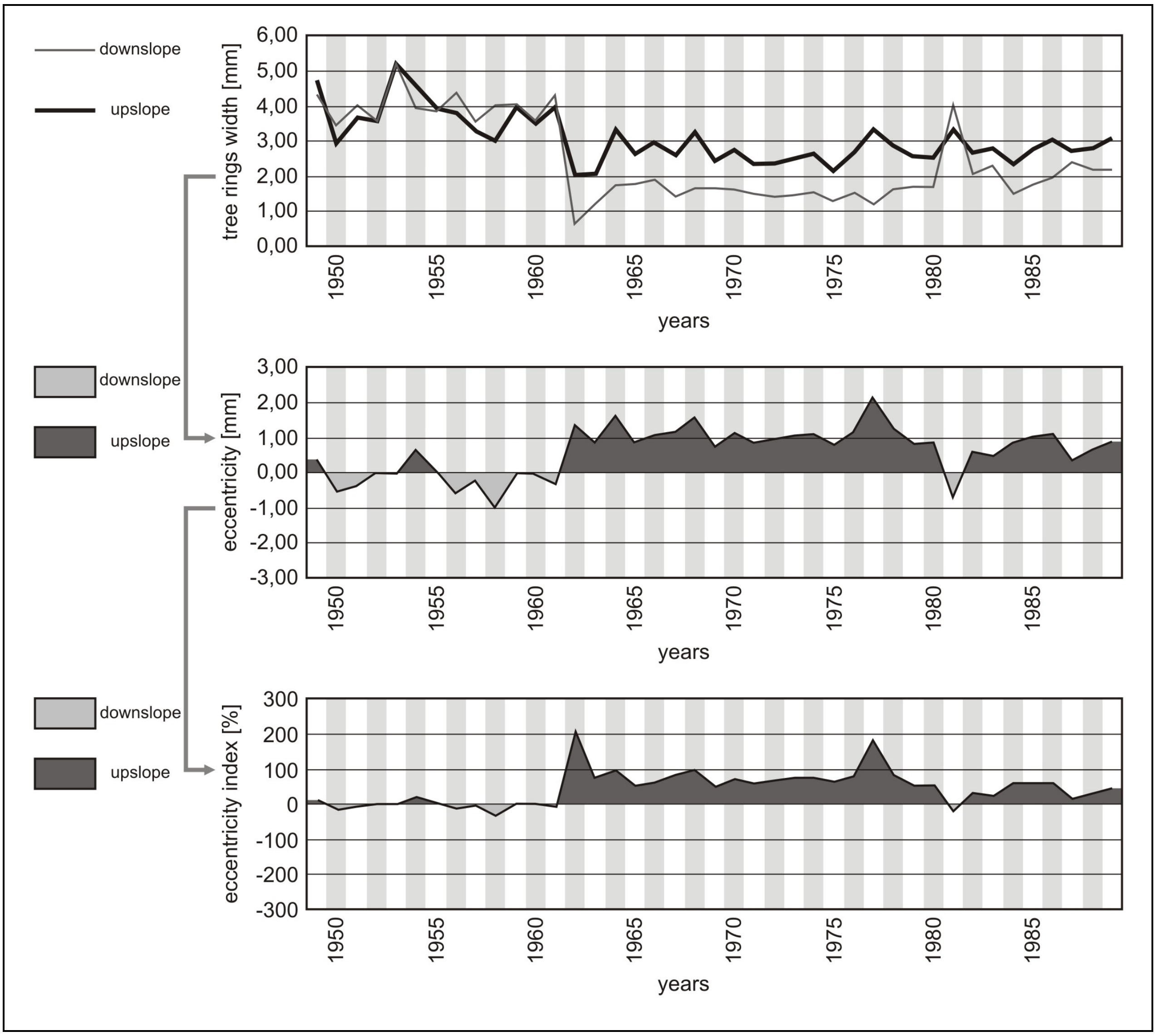

Figure 2: An example of raw data convertion and graph transformation: from tree-ring width [mm] into eccentricity index (for location of analysed sample Kp 2/1 – see figure 4).

The reference site Kp R

The reference site is located outside the boundaries of the large landslide (Fig. 3C). The slope is supported by a colluvial mound (part of the landslide tongue), which thus prevents it sliding. The surface of the slope is smooth. There is no geomorphological evidence of mass movement at this location.

The eccentricity indices of individual tree rings from the reference site rarely exceed 100%/-100% (upslope/downslope eccentricity). There is a balance and constant transformation between the upslope and downslope eccentricity (e.g. sample Kp R/1 on Figure 5). The eccentricity indices oscillate around a value of 0% (lack of eccentricity). The tree is continuously balancing to maintain its stability in response to wind, snow mass, soil creep, tilting and sliding under the tree’s own constantly increasing weight.

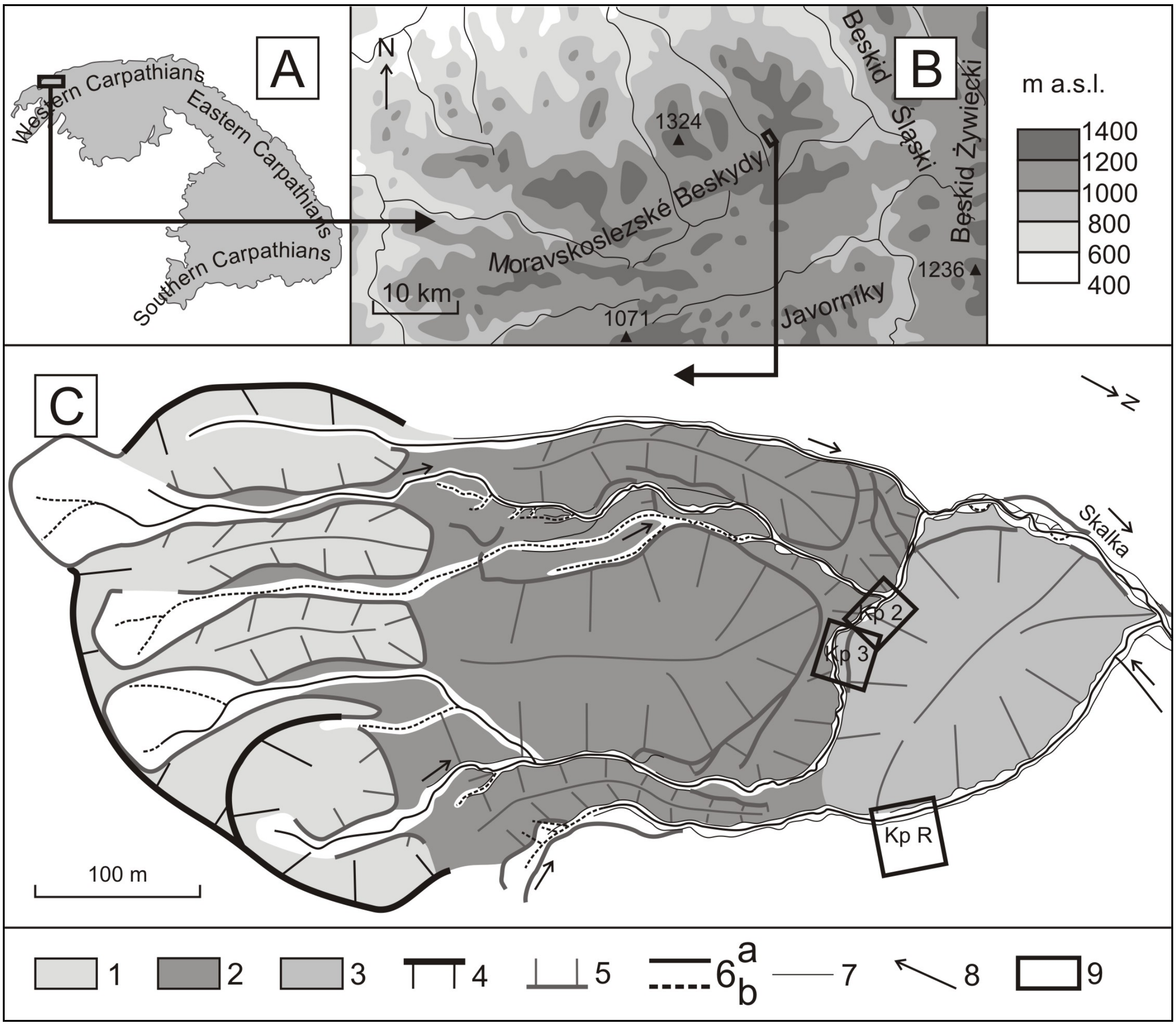

Figure 3: Location of the Skalka study area in A – the Carpathians , B – the Moravskoslezské Beskydy mountain range. C – The Skalka study area – large landslide – with the location of the reference site Kp R and study sites Kp 2 and Kp 3;
Legend: 1 – landslide niche, 2 – landslide tongue, 3 – landslide tongue: a colluvial heap, 4 – headscarps, 5 – escarpments, 6 – channels: a – active, b – inactive, 7 – channel undercuts, 8 – flow directions, 9 – study and reference sites.

Study sites Kp 1 and Kp 2

The study sites are located in the lowest part of the toe of a large landslide, on the colluvial mound (relative height: 60 m; Fig. 3C). Geomorphic mapping conducted on the slope investigated revealed the occurrence of cracks, crevices, headscarps and small toes descending from the slope to the stream channel. The relative height between the headscarps and toes is up to 1 m. The average gradient of the slopes is ~50%. Spruces growing on both study sites are tilted and some of them have deformed stems (Fig. 1).

Both slope and tree morphology suggest that active landsliding, and perhaps also lateral spreading, of the summit section of the mound are occurring. The morphology of the channel of the Skalka at the study sites is characterized by:

1. sinuosity imposed by the lateral delivery of colluvial material,
2. distinct traces of lateral erosion, particularly on the bank opposite the active slope.

Therefore it seems that the channel of the Skalka in the sections investigated is being pushed away by small (~30 m long) landslides.

The eccentricity indices of tree rings from the study sites Kp 2 and Kp 3 show a particular pattern. In the upper parts of the slope studied, the pattern at the start of tree growth is similar to that from the reference site in the case of trees tilted upslope. Afterwards abrupt jumps in the value of the eccentricity index occur: from about 0 to >100% (upslope eccentricity). These years can be described as the moment when mass movement of the slope was activated (Fig. 5: samples Kp 2/15, Kp 3/3). Trees growing in the lowest parts of slope, near the stream channel, are tilted downslope and represent a different eccentricity pattern (Fig. 5: Kp 2/6). Usually they have a clear downslope eccentricity from the very start of their growth. Jumps of the eccentricity index curves can reach -500%. This situation can be treated as a record of fluvial bank undercutting and the shallow sliding associated with this.

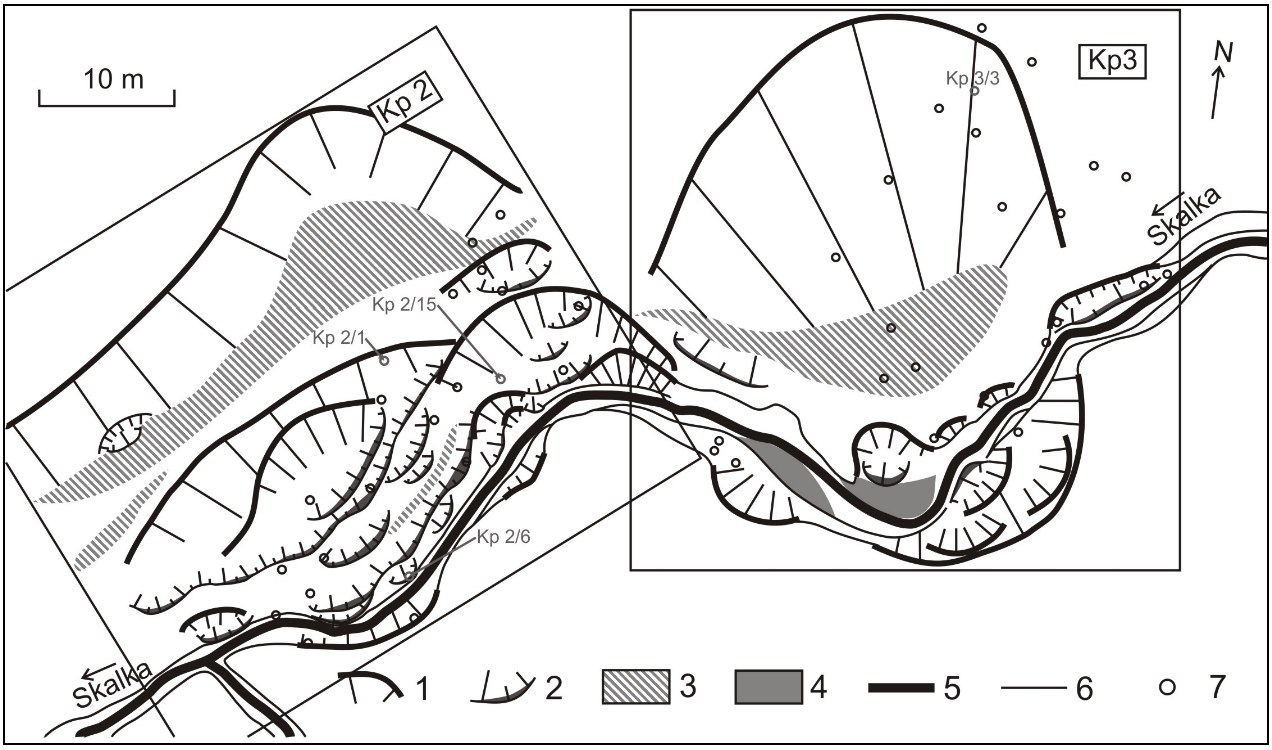

Figure 4: Morphology of the study sites Kp 2 and Kp 3. Location of trees sampled; legend: 1 – headscarps, 2 – landslide tongues, 3 – slope trenches, 4 – alluvial bars, 5 – channel, 6 – channel undercuts, 7 – sampled trees.

Conclusions

Tree-ring eccentricity is a good sensor for analysing mass movements. The eccentricity index enables one to compare trees growing in different conditions and assess the intensity of their eccentricity and by this, the intensity of mass movement. Spruces growing on unstable slopes are significantly more eccentric than trees from the reference site. The eccentricity method allows one to distinguish shallow slope movements (soil creep on the reference site) from relatively deep seated movement (landslides on the study sites).

On a stable slope (reference site) trees show minimal values of eccentricity index and a balance between the up- and downslope eccentricity. Spruces growing on the upper part of the active slope (study sites) are only tilted by mass movements and their rings are significantly wider upslope. Trees undercut by the stream produce rings which are much wider downslope.

Studies of eccentricity allow to:

a. distinguish geomorphic processes induced by mass movement and stream erosion,
b. distinguish zones where trees were tilted by lateral erosion of streams from areas dominated by the impact of mass-movement,
c. date the occurrence of mass movement on slopes and erosional events in the channel.

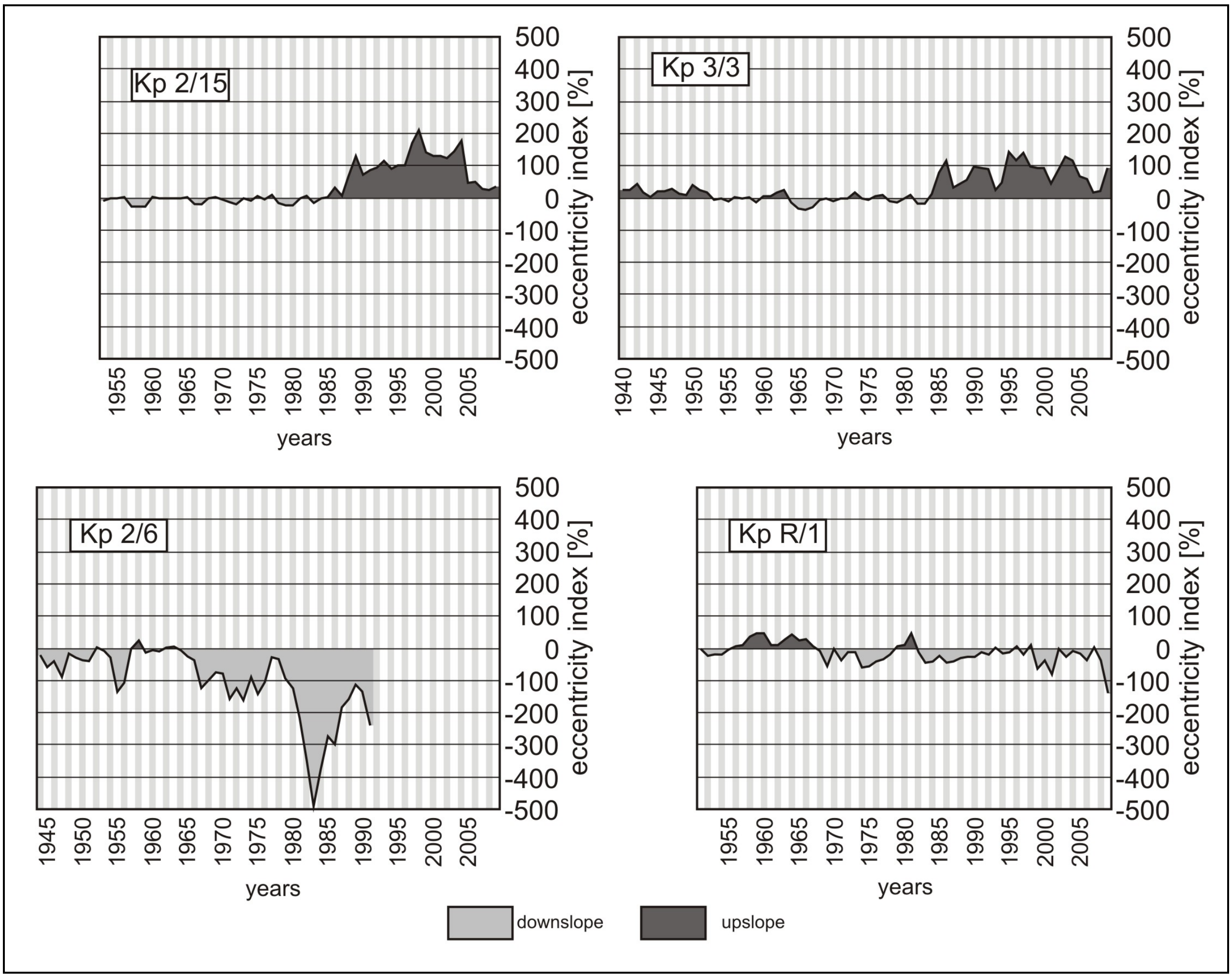

Figure 5: Examples of eccentricity index graphs from both study sites, from upper part of slopes (Kp 2/15,Kp 3/3), from the near-channel zone (Kp2/6) and from the reference site (Kp R/1) (for location of analysed samples – see figure 4).

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SECTION 3

ARCHAEOLOGY

The development of a long pine (*Pinus wallichiana*) chronology from western Nepal from living trees and ^{14}C-dated historic wood samples

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Introduction

Western Nepal is a remote mountainous region in the central Himalaya that has been poorly studied by means of dendrochronology so far (Bhattacharyya 1992; Cook et al. 2003, 2010, Bräuning 2004). The Dolpo district is located in the inner Himalaya north of the Himalayan crest line and is therefore located in the relatively dry lee side of the Indian Summer Monsoon. *Pinus wallichiana* is one of the dominating tree species in higher elevations and has widely been used for constructing purposes. In the neighbouring Upper Mustang area farther to the east, pine tree-ring series collected from historic settlements have been successfully crossdated to chronologies from living trees, resulting in a chronology spanning almost 700 years (A. D. 1303-1996) (Schmidt 1993; Schmidt et al. 1999, 2001; Gutschow 1994; Gutschow et al. 2001).

Bräuning et al. (2004) had constructed a chronology of living *P. wallichiana* samples from relict sites in the upper Dolpo region (82°54' E, 29°26' N; 3850 m a.s.l.) spanning a 443-year period from A. D. 1556-1998. In addition to the living trees, increment cores from timber of historic Buddhist monasteries were collected. However, although younger historic material could be successfully dated (Bräuning 2004), we were unable to synchronize other historic wood samples, even though they contained a sufficient number of tree rings. Preliminary climate-growth analysis indicated ring-width variations of *P. wallichiana* to correlate to precipitation during the summer monsoon season (April to September) (Bräuning 2004). Thus, we tried to extend our existing pine chronology into the past by means of radiocarbon analysis to reconstruct precipitation variations during climate episodes of particular interest like the medieval warm period.

Material and Methods

Historic samples of *P. wallichiana* from four monasteries, Lang Gompa (three samples), Nesar Gompa (two samples), Samling Gompa (two samples) and Tsakhang Gompa (two samples), were collected. Tree species had been determined by anatomical means. Width of the historic tree-ring material was measured on a LINTAB II measuring system (Rinntech, Heidelberg, Germany). We applied AMS age determinations in the Erlangen radiocarbon laboratory to tree-ring series that could not be crossdated to the existing chronology either due to the shortness of the sequences or due to an age older than the chronology. As generally known, individual radiocarbon dates yield multiple results and do not allow straightforward dating due to variations in the radiocarbon calibration curve. However, by defined age differences (e.g. by counting tree-ring numbers) of several consecutive radiocarbon samples it is possible to match the radiocarbon ages of these samples to the 'wiggles' of the radiocarbon calibration curve. This so-called wiggle match technique permits to constrain the probability distribution of the calibrated radiocarbon result and to exclude those dating intervals that become extremely unlikely. The wiggle matched ages for this study were calculated at the 68.3% confidence limit using the D_SEQUENCE function of the radiocarbon calibration program Oxcal 3.10 (Bronk Ramsey et al. 2001) with INTCAL04 (Reimer et al. 2004) as calibration curve.

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Results and discussion

In total, 25 AMS-ages from nine wood samples were measured. An example of a successful wiggle match dating is shown for sample NLG4_8 from Lang Gompa, where a normal calendar age calibration (calibration also by Oxcal 3.10 using INTCAL04) of three ^{14}C-samples revealed multiple results that nearly cover the whole time interval from 1650 AD to 1950 AD (Table 1). By applying the wiggle matching method the possible calendar age intervals could be considerably constrained. A dating check with the Dolpo chronology at the suggested AMS-age position resulted in a probable dendrochronological position of the sample. Nevertheless, the test statistics are not very strong (sign-test 68% [p<0.01]; t-test after Holstein: 2.7; t-test after Bailie/Pilcher: 1.9, Figure 1), which is probably related to individual disturbance signals in the sample.

Table 1: AMS ^{14}C dating results for samples from monastery Lang Gompa (Dolpo region, Nepal)

Lab code	**Sample Name**	**BP**	**δ ^{13}C**	**Cal AD (1 σ) without Wiggle Matching**	**Cal AD (1 σ) with Wiggle Matching**
Erl-13059	NLG4_8, rings 1-4	145 ± 40	-21.1	1673 AD - 1697 AD (10.2%) 1725 AD - 1778 AD (23.0%) 1799 AD - 1814 AD (6.7%) 1835 AD - 1877 AD (16.9%) 1917 AD - 1942 AD (11.4%)	1678 AD - 1695 AD (17.4%) 1719 AD - 1738 AD (34.6%) 1879 AD - 1892 AD (16.2%)
Erl-13060	NLG4_8, ring 31	123 ± 40	-20.5	1683 AD - 1735 AD (20.9%) 1805 AD - 1891 AD (37.8%) 1908 AD - 1930 AD (9.4%)	1708 AD - 1725 AD (17.4%) 1749 AD - 1768 AD (34.6%) 1909 AD - 1922 AD (16.2%)
Erl-13061	NLG4_8, rings 62-63	223 ± 40	-21.5	1644 AD - 1680 AD (29.9%) **1764 AD - 1800 AD (28.3%)** 1939 AD - 1953 AD (10.0%)	1739 AD - 1756 AD (17.4%) **1780 AD - 1799 AD (34.6%)** 1940 AD - 1953 AD (16.2%)

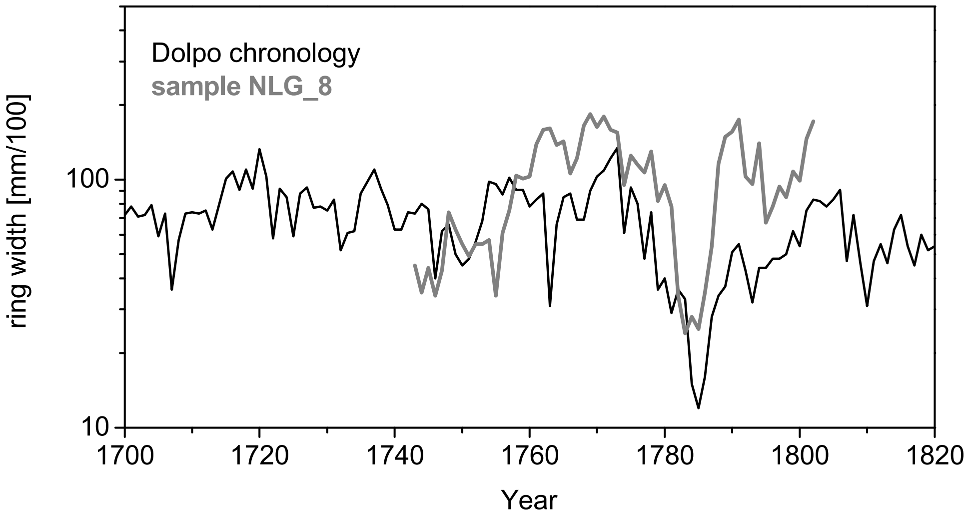

Figure 1: Curve of sample NLG4_8 displayed against the Dolpo chronology at the position suggested by the wiggle-matching procedure A.D. 1743-1804.

The present state of chronology development for the Dolpo area is shown in Fig. 2. It consists of Dolpo chronology (living trees) spanning 443, years back to 1556 AD as well as floating tree-ring series dated by radiocarbon. Some samples date back into the 7th century A.D. and are to our knowledge the oldest tree-ring samples collected in western Nepal.

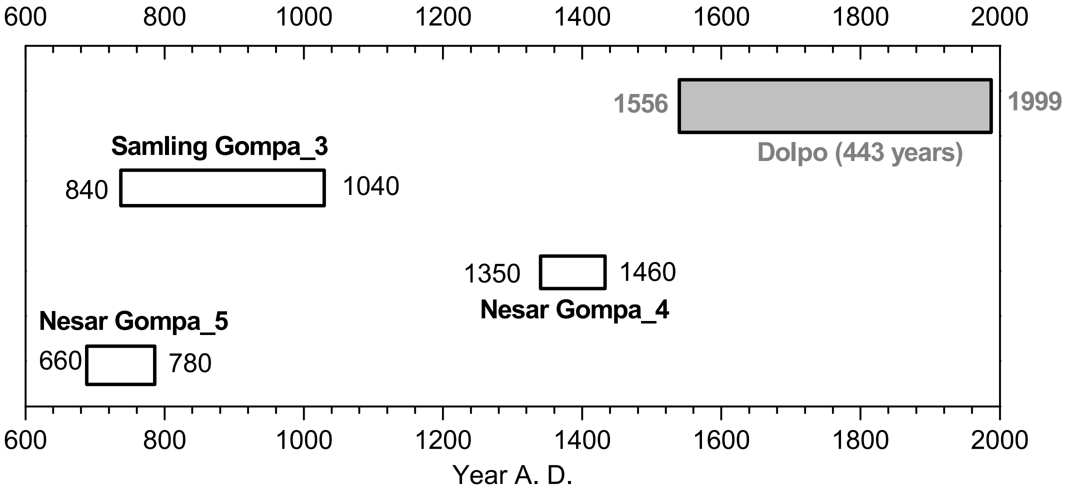

Figure 2: Length of the existing Dolpo pine chronology from living trees (grey bar) and dates of floating ^{14}C-dated historical wood samples collected from different monasteries (empty bars).

Conclusions

The first results of our study demonstrate the potential of radiocarbon wiggle-match dating applied upon historic tree-ring material. Collecting and dating additional pine samples from historic objects (e. g. Schmidt et al. 1999, 2001; Gutschow 2001) may lead to a tree-ring chronology spanning more than a millennium. It might also replenish the very limited palaeoclimatic information from this vulnerable high mountain region (Cook et al. 2003, 2010). An existing gap of precipitation-sensitive tree-ring sites between western Himalaya and Karakorum (Esper et al., Treydte et al. 2006) and the central Tibetan plateau could be closed as well. Furthermore a closing of the yet existing gaps in the chronology may provide an important tool for dendrochronological dating of objects of great cultural value.

Acknowledgments

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Pile-dwellings at lake Degersee (SW-Germany) – a challenge for dendrochronology

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Settlement setting and archaeology

Lake Degersee is located 5 km northeast of Kressbronn (Baden-Württemberg, Germany), within the drumlin landscape of Allgäu. Interpreting pollen and charcoal contents in laminated lake deposits at the adjacent lake Schleinsee, Clark et al. (1989) found first evidence of human occupation through time at those lakes. Archaeology, archaeobotany, palynology, limnology, geoecology and dendrochronology are interwoven in a new project, initiated in 2008 and co-financed by the German Research Foundation. The aim of this study is to investigate human settlement activities of the Neolithic period and their environmental background on a marginal position east of the main lake-shore settlement area of Lake Constance.

There are two known settlement places at lake Degersee, DeI and DeII (Fig. 1), discovered before and during the project, respectively. Underwater excavations had been carried out at both places, but the main focus was on Neolithic settlement phases of DeI.

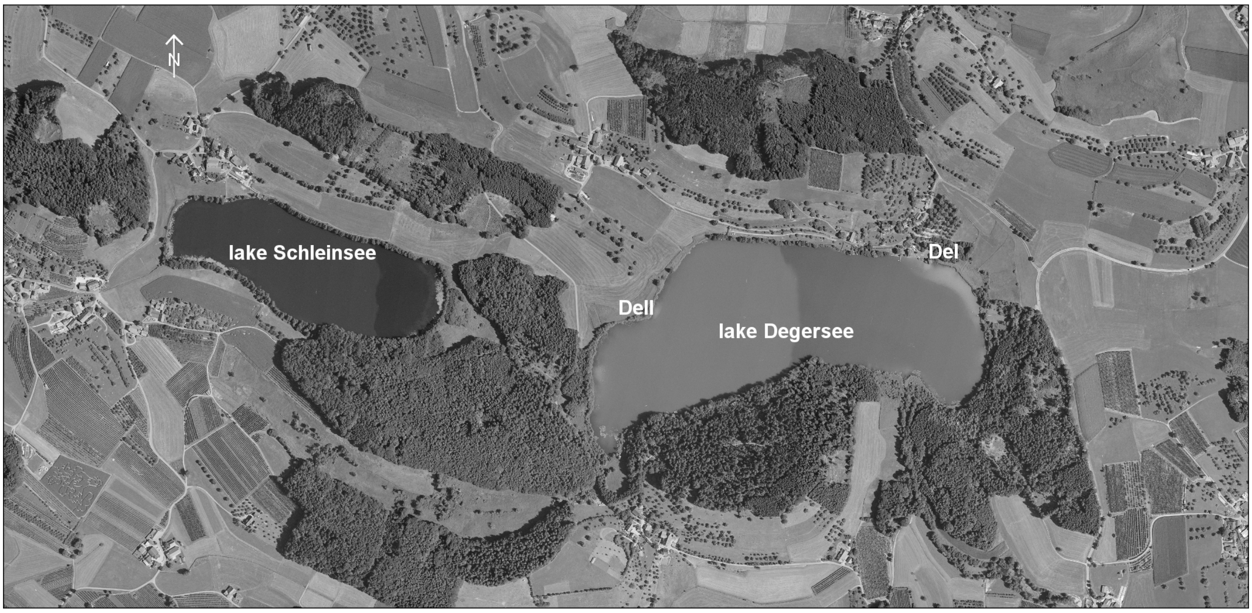

Figure 1: Aerial picture of lake Degersee, lake Schleinsee and surroundings. The Neolithic settlements DeI and DeII are indicated at the shore. In the drumlin landscape, hill tops are covered with mixed forest of broad-leaved and conifer tree species. Source: Bayerische Vermessungsverwaltung, modified.

At the present time, precipitation exceeds 1,000 mm at lake Degersee. The same factor probably limited agriculture during the Neolithic period, whereas animal husbandry and hunting must have played a larger role. This assumption is in agreement with the geoecological site catchment carried out by Baum (2010).

Within the framework of this project, the dendrochronological tasks were i) to outline the choice of tree species for building purposes on the basis of wood anatomical analysis, ii) to build a site chronology, also with the aid of heteroconnections, iii) to identify building structures and iv) to achieve ecological information out of tree ring data.

Timber use

In total, 1,286 timbers have been excavated at Del, consisting of 833 piles and 453 stratified woods, which were embedded in distinct layers. The mainly used tree species by Neolithic settlers was ash (*Fraxinus excelsior* L., Fig. 2). Generally, constructions of this timber have a durability of about three years (Luley 1992), thus ash is not well suited for building purposes in wet conditions. Alder (*Alnus sp.*), maple (*Acer sp.*), poplar (*Populus sp.*), hazel (*Corylus avellana L.*) and willow (*Salix sp.)* were also used frequently. Oak (*Quercus sp.*), usually the preferred timber species for pile-dwelling constructions at Lake Constance, had only been utilized during the last settlement phase D (Horgen culture, Fig. 3D). Comparing the mean diameters in Tab. 1, one can distinguish between two groups of about 7.50 cm and circa 4 cm. Alder, maple and willow belong to the first mentioned group, hazel and poplar to the second one.

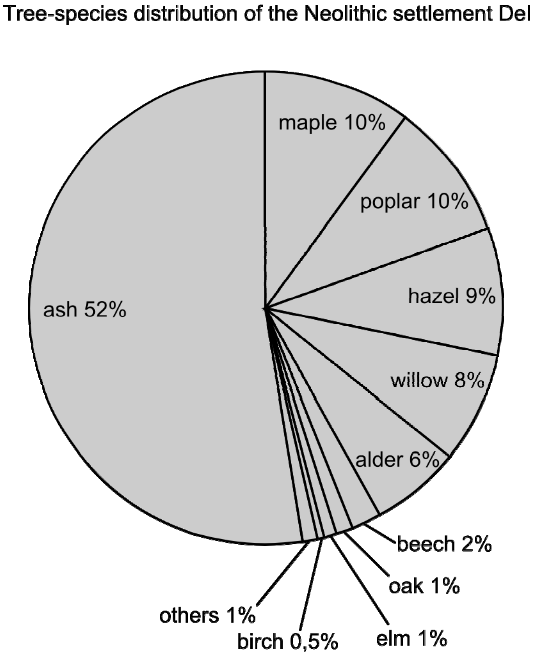

Figure 2: Timber species distribution of all settlement phases at the Neolithic settlement Del.

Table 1: Tree species, mean diameter (d) and related number of samples at the Neolithic settlement Del (samples which possess pith and waney edge only).

Tree species	d [cm]	Quantity
alder	7.11	48
ash	7.88	375
beech	4.07	22
birch	3.33	3
elm	8.50	6
hazel	3.78	89
maple	7.35	74
oak	14.00	1
poplar	4.65	74
willow	7.20	81

Along with the proportion of the tree species (Fig. 2), mean diameter (Tab. 1) and planigraphic distribution of piles show that only ash, oak and willow were assuredly used for buildings. The use of the other tree species is still not clear.

With regard to the shape of the stem cross sections, most are circular (piles 91 %, stratified woods 71 %). Only in case of the stratified woods, 18 % are half split (3 % of the piles). More split cross sections exclusively show the eight oak piles of phase D (Horgen culture, Fig. 3D).

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Dendrochronology and site chronology

The shores of lake Degersee had been visited at various times in the past. Beginning around 5,200 BC (first evidence of Linear Pottery in the region, Fig. 3A), we know that settlers came back 1,200 years later and several times after that. The youngest item remaining of human activity, dating back to the prehistoric period, is a logboat made of alder (Fig. 3E). Phases A and E are still without evidence of layers and structures.

Tree ring investigations presented in this paper correspond to the three intermediate settlement phases B, C, D in Fig. 3. Due to the presence of oak wood and the chances for dendrochronological application of this tree species, eight piles are dated to 2956 BC (Fig. 3D). Heteroconnections have been made to try to date earlier occupation phases, but first results had to be supported by radiocarbon dating. Because of the high incidence of ash, the main focus was on the dendrochronological evaluation of this species. Within this analysis, dendrotypology plays a key role along with the development of dendrogroups (Billamboz 2006).

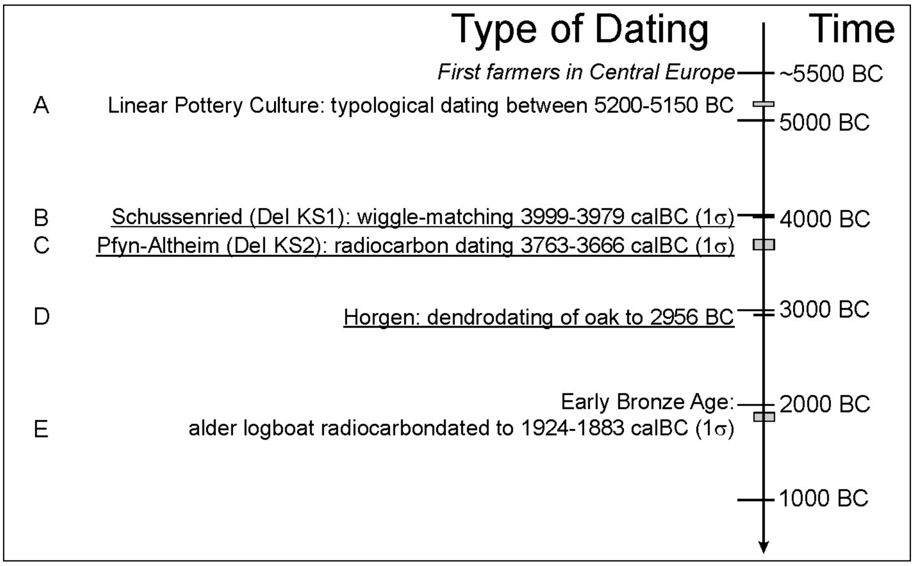

Figure 3: Settlement phases (A-E) and type of dating. Underlined are the settlement phases with remains of settlement items and not underlined are the findings without secured evidence of a settlement at Del.

In total, tree ring width was measured on 593 wood samples. Tree species and their respective number of dendrochronological analyzed woods are given in Tab. 2. With exception of the few oak samples, which have a large average number of rings, the length of the series are distributed into two classes, 46-48 years for ash, beech, maple and 12 to 23 years for the remaining tree species. Mean tree ring width shows the same classes as tree ring number. On account of planigraphic distribution, the main focus of further dendrochronological analysis was on ash, oak and willow.

Table 2: Wood sample statistics related to tree species and tree ring width measurement (N= number of measured samples; N_{tr}= mean number of tree-rings, i_r= mean radial increment).

Tree species	**N**	**N_{tr}**	**i_r [mm]**
alder	33	22.5	2.12
ash	407	48.2	0.97
beech	16	48.1	0.68
hazel	23	11.8	2.03
maple	59	46.7	1.14
oak	12	82.2	1.14
willow	43	14.7	3.36

166 ash samples, piles and with help of stratified woods, can be assigned to phase B (Schussenried culture). The result is a 106 year ash chronology (m500, Fig. 4A) with four-year felling activities. There are several Early Neolithic settlements in Upper Swabia and at Lake Constance, where ash was used for constructions. With regard to the synchronisation and dating possibilities of ash, Hetzer (2008) found only weak correlations between site chronologies on a transect between Lake Constance and Upper Swabia. Crossdating ash chronologies along these distances did not give a reliable result and unfortunately, only few reference chronologies are known for the considered time period. Therefore a wiggle-matching with four samples was performed on the single series of an ash pile with 88 tree rings, whose last ring was formed in early 40th century BC (Fig. 3B, Fig. 4B, C).

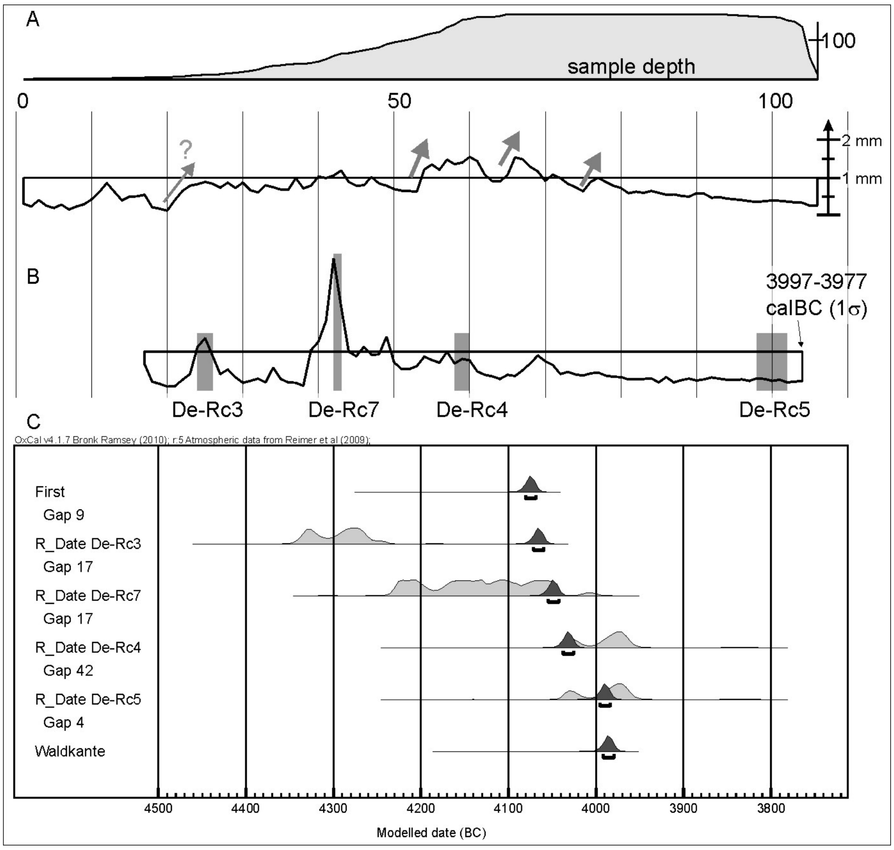

Figure 4: Towards the absolute dating of ash chronology m500: A: ash site chronology m500 and sample depth (max. 166). Gray arrows indicate releases in radial growth on m500 (horizontal line in A and B is 1 mm increment level, see right-hand scale at m500, raw values), B: position of ^{14}C-samples (grey rectangles and labelled below) for the wiggle matching on the single series DC 5119, which is dated between 3997 and 3977 calBC, C: Multiplot of the wiggle-matching samples De-Rc3 to De-Rc7 in OxCal.

Identification of building structures

There was planigraphic evidence and dendrochronological proof of buildings constructed of oak and of willow (Fig. 5). The oak construction is dendrodated (Fig. 3D), radiocarbon dating of the willow construction indicates a position in the second half of the 3rd millennium. With an average number of 15 tree rings, willow tree ring series are very short (Tab. 2), but show a clear result with the identification of a building structure in Fig. 5.

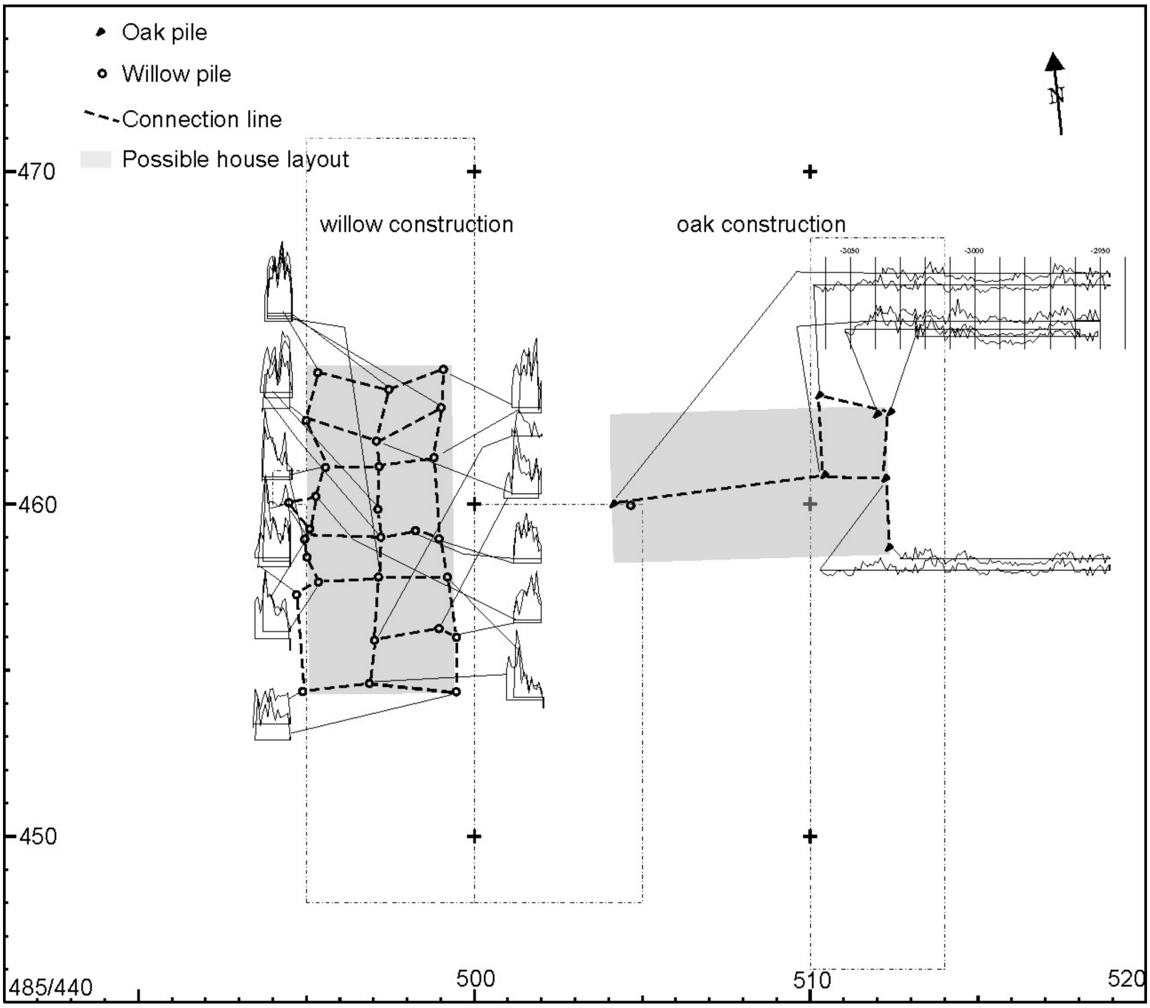

Figure 5: Building structures and two cases of tree ring application: left-hand - structure identification by cross dating of short willow series on relative scale; right-hand, oak structure of phase D (lines indicate connection between piles and growth pattern, respectively).

In contrast to the lake-shore settlement of Hornstaad Hörnle Ia at Lake Constance, where Billamboz (2006) could outline a clear map of house units for a similar time period as phase B (Schussenried) at DeI, the distribution of the ash piles do not indicate any pattern or cluster. Neither the orientation nor a delineation of building structures could be determined. Attempts at sorting piles by the number of tree rings, the orientation of pile rows, the pile shape or diameter did not lead to a satisfyingly result. Moreover, cross correlation of single ash series (methodology: Lambert et al. 2006) associated to phase B (Schussenried culture), demonstrates an arbitrary form of timber supply without selection, with regard to tree age or timber dimensions (Fig. 6a). The dendrochronological comparison of growth patterns in Fig. 6b leads to the same conclusion.

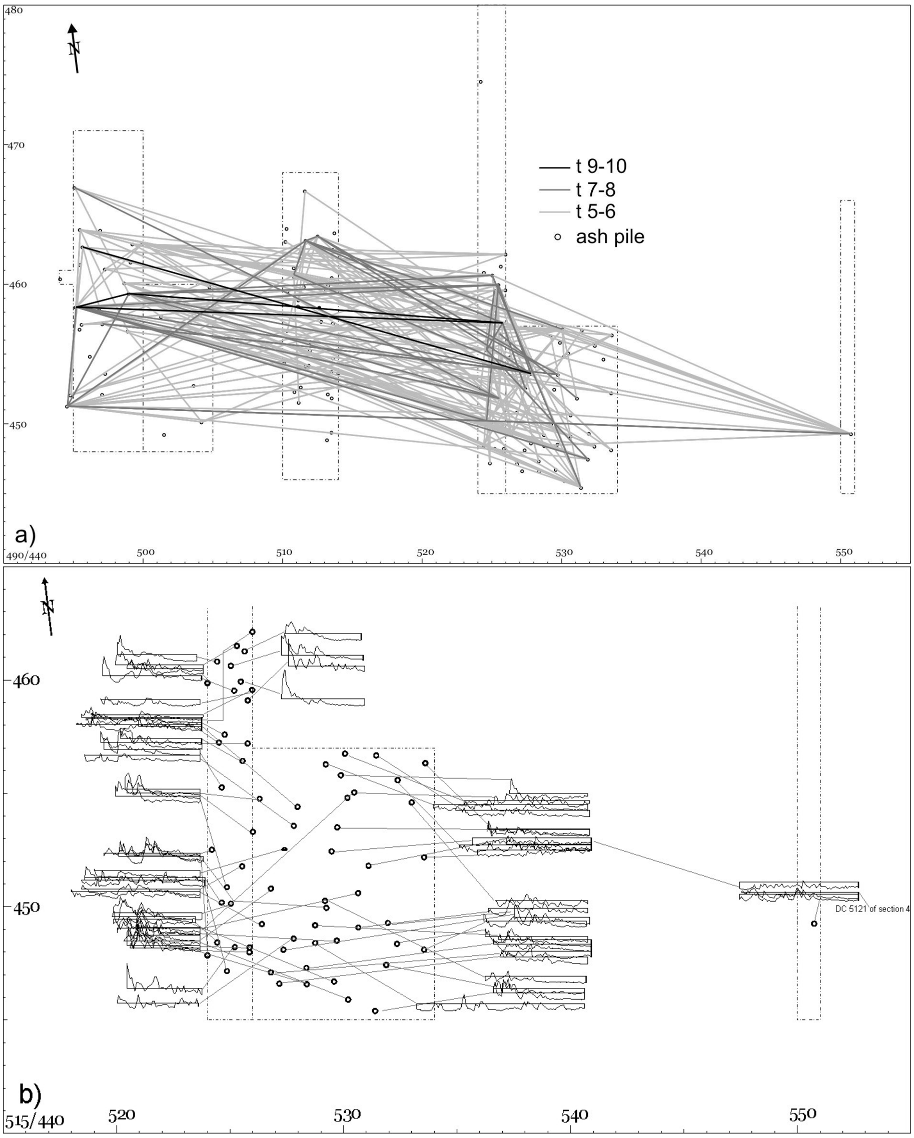

Figure 6: Two steps within the synchronization process of ash piles referred to the phase B (Schussenried culture): a) cross correlations between all ash piles distributed in the excavation units (dot-dashed line), different classes of t-values (Ballie/Pilcher 1973) are represented by lines of different grey scale (methodology: Lambert et al. 2006), b) pile distribution along with the dendrotypological assemblage of their tree ring series according to growth pattern and number of tree rings.

Archaeological tree ring data and dendroecological perspectives

Beyond the chronological aspects of dating, archaeological tree ring material can also be used for ecological evaluations. The first consideration refers to timber supply, or to be precise the amount of timber needed to construct one house of the Schussenried culture (corresponding to phase B) and the crown area (c_a) of particular trees. The crown area is the two-dimensional projection of a crown outline on the ground to determine the area one tree needs in a forest stand. Hein (2004) developed the formula $c_w=0.698+0.203\cdot dbh-0.022\cdot a$ to calculate the crown width (c_w) of a single ash tree, using the age (a) and diameter at breast height (dbh). To compute c_a out of c_w, the formula $c_a=c_w^2\cdot\pi/4$ was used. Dbh and age are obtained from the tree-ring data of measured ash samples, adding in an estimation of bark thickness. Hein (2004) points out, that with a dbh of 10 to 15 cm the length of a trunk free of knots varies between 3 and 9 m. Hence, most construction woods for this calculation derive from one trunk.

Due to destruction processes lasting 6,000 years, now, there is no entire house left. Luley (1992) calculated the wood supply of a house of the type Hornstaad (cultural group, about 70 years prior to the Schussenried culture), with similar house dimensions. Beginning with the substructure up to the rafters, 133 woods of different length are needed to build one whole house of this type. To reconstruct the timber supply for one house of the Schussenried culture, this data was taken from Luley (1992) and adapted to the case of phase B in DeI. The result of this calculation is a total ash tree crown area of 202 m², with dbh's ranging from 8 cm to 15 cm. In agreement with geomorphological results around the settlement of DeI, Neolithic settlers should have had no difficulties finding this amount of timber in surrounding forests. Ecological analysis is still going on with reconstructing the former landscape by combining geomorphological, botanical and dendrochronological data.

According to the four year cutting period, shortness of settlement occupation at DeI is similar to ash and oak building phases at Hornstaad (Billamboz 2006). Using a timber species with poor durability in wet conditions, it seems that those settlers did not plan to stay a long time at the shore of lake Degersee. Billamboz (2006) and Bleicher (2009) assume a short term cyclic relocation of settlements between 4000 BC and 3000 BC. At lake Degersee, pollen and macroremain analysis point to agriculture usage and animal husbandry. A geomorphological survey around the settlement of DeI detects a first colluvial formation in the Early Bronze Age. Therefore, no large opening of the landscape took place in earlier time periods.

Tree ring width of chronology m500 (Fig. 4) decreases to low values in the last 25 years before the construction of the settlement of phase B at DeI. Low radial increments and a mean sample diameter of 7.8 cm (Tab. 1) with an average of 48 growth rings (Tab. 2) point to dense conditions in the forest stands. The grey arrows in Fig. 4A indicate radial increment releases 30, 40 and 50 years before settlement of phase B. These could be caused by human activity in those forest stands. Clark et al. (1989) obtain similar conclusions by pollen analysis showing short term increase of pioneer tree species like hazel, often followed by ash. Subsequently, these secondary forest formations were sometimes superimposed by the longer lasting cycle of beech, while at the same time settlement activity was reduced. Ash, as an intermediate species of light sensitivity, and its regeneration potential presumably played a key role in the assumed cyclic settlement process in the region at lake Degersee. Within ash's water, light and nutrient demands, named regeneration potential and its capacity to colonize a wide span of sites are illustrated in other regions, for example in the Pyrenees on pastured surfaces which are being reafforestated now (Mdawar 2009, e.g. Fig. 7). This aspect is of particular interest and should be evaluated with respect to local pollen diagrams, where ash shows typical peaks of development after clearing activities and before the climax forest development. From this perspective it appears clearly that the information potential of ash has to be evaluated more in an ecological than in a climatological way.

Figure 7: For comparison, example of ash regeneration on the French Jura plateau (Chantrans, F). Source: A. Billamboz.

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Old wood - new investigations. Dendrochronological results on mining timber from the prehistoric copper mine Kelchalm/Kitzbühel

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Introduction

Metal mining activities in the Alpine region go back to prehistoric times. The earliest findings derive from the region of Schwaz/Brixlegg in the lower Inn valley, Tyrol, Austria (Fig. 1).

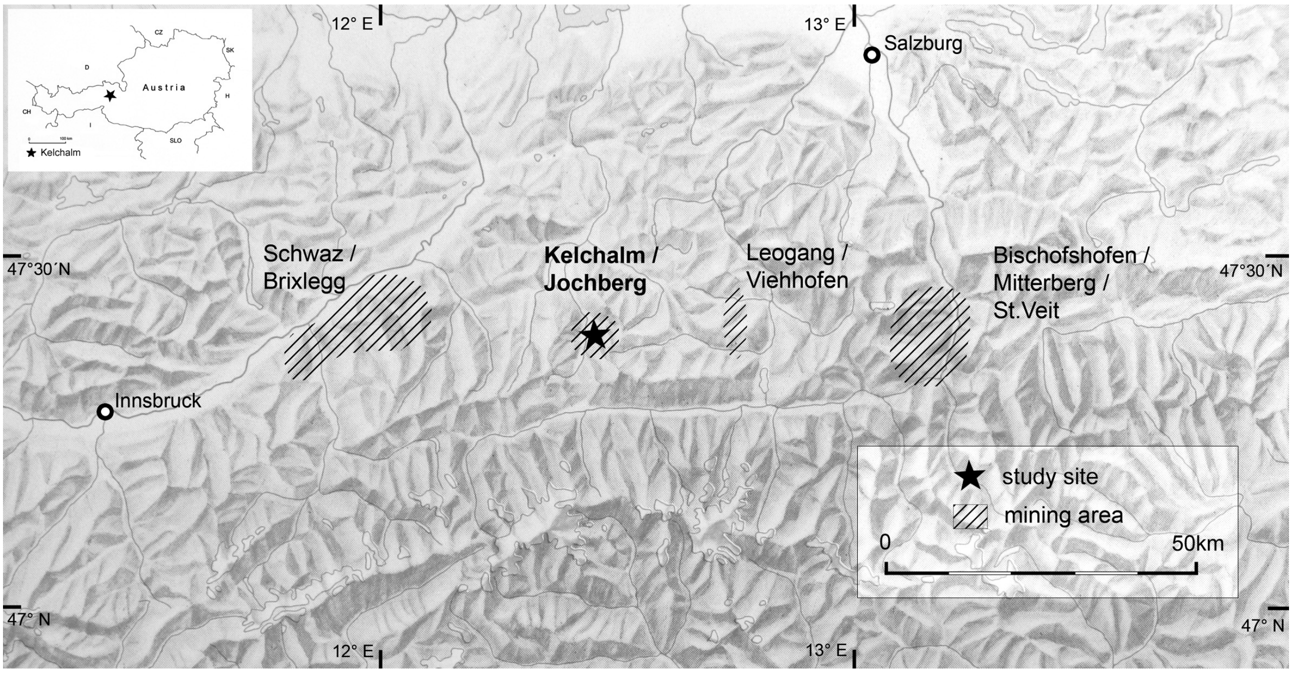

Figure 1: Location of the prehistoric copper-mining areas in the northern part of the Eastern Alps (map: Alpen Reliefkarte - Tirol Atlas, Institute of Geography, University of Innsbruck).

Archaeological excavations (1932-1953) proved prehistoric mining even in the region of the Kelchalm (E 12°27´, N 47°23´; Fig. 2). Based on the typology of ceramic and metal artefacts found together with wooden objects at the Kelchalm, Richard Pittioni stated, that the mining activities in this region started at the turn of the 2nd to the 1st millennium BC (Pittioni 1968). These wooden artefacts excavated by Richard Pittioni and Ernst Preuschen are stored in the Museum of Kitzbühel. Renewed archaeological excavations at the Kelchalm site were carried out by Michael Klaunzer and his team in 2009. The area of interest, the so-called Scheidehalde 50 (separation heap) is located close to the area, which was investigated by Pittioni and Preuschen already. Besides ceramic artefacts, some stone fragments, several bones, and a huge number of wooden samples (e.g. woodchips) were recovered.

Both, the exhibited wooden remains of the Museum Kitzbühel and the samples derived from the excavation in 2009, were dendrochronologically investigated. Some results of these dendrochronological investigations are published already (Pichler et al. 2009).

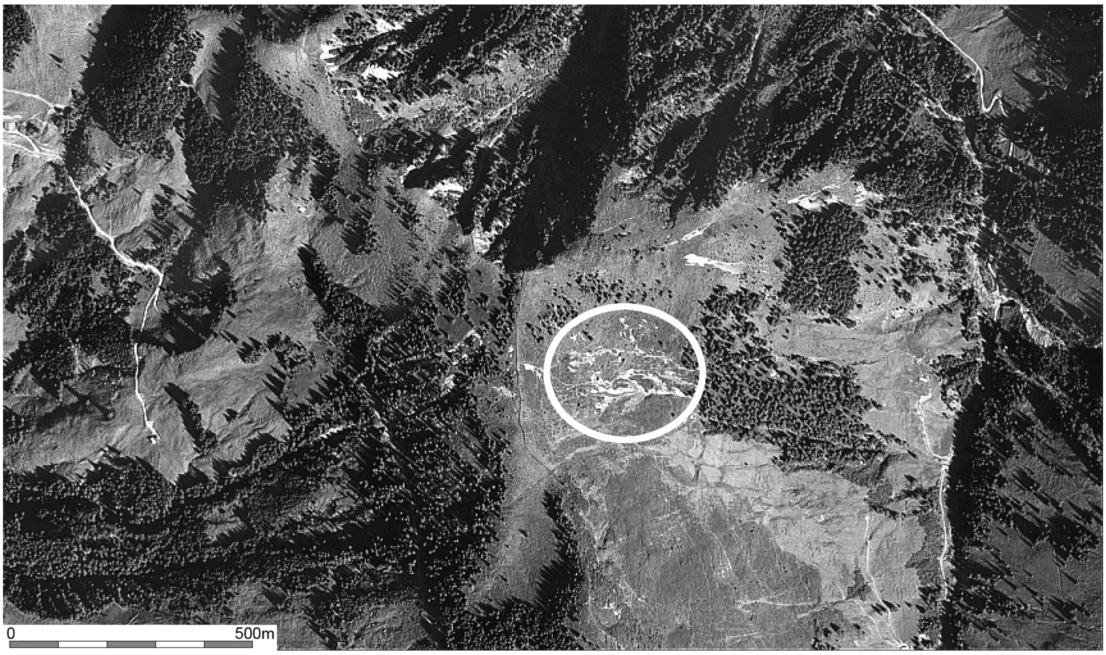

Figure 2: Arial view of the Kelchalm copper mining site (approx. 1700 m a.s.l.). The dendrochronologically analysed objects originate from the area within the white circle (source: Land Tirol).

The main goal of this study was to date the prehistoric wooden remains from the Kelchalm site, which partially have been excavated 50 years ago. These dendro-dates will enhance the chronological understanding of the development of mining in the Alpine region. Additionally, the species used for the artefacts probably show a specific selection, according to their properties.

Material and Methods

After a screening of the wooden artefacts regarding dendrochronological techniques (e.g. appropriate number of tree-rings, wood wane) tree-ring width (TRW) measurements were carried out on 57 samples (e.g. Fig. 3, Fig. 4). TRW-measurements on the selected artefacts were performed either by means of the LINTAB measuring device or image-analytic methods.

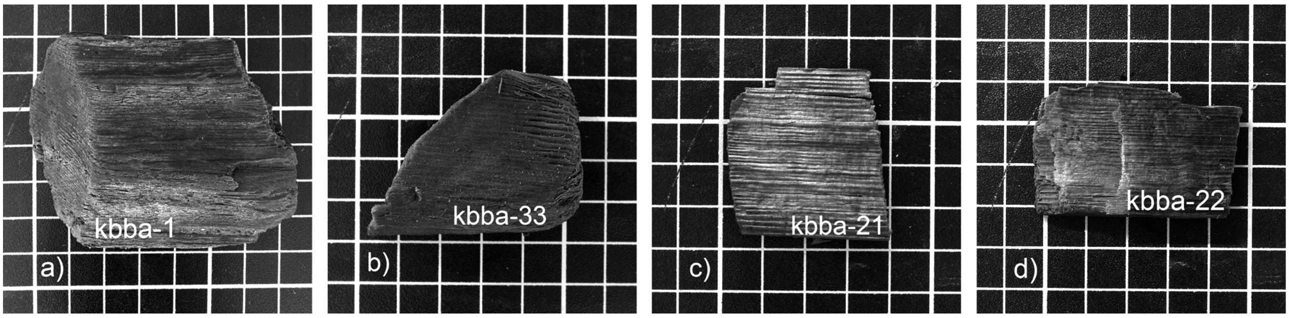

Figure 3: Dendrochronologically analysed woodchips derived from the archaeological excavation of summer 2009. a) chip with 78 measured tree rings, dendro-date 1262 BC; b) chip with 35 measured tree rings, dendro-date 1252 BC; c) chip with 38 measured tree rings, felling date autumn/winter 1243/42 BC; this chip derives from the same log as chip kbba-22; d) chip with 31 measured tree rings, felling date autumn/winter 1243/42 BC (photos: T. Pichler, 2009).

We also determined the tree species and - for samples without pith - extrapolated the pith age. Based on several measured radii per artefact, average curves of each object were established. The Kelchalm sample series were then compared with the Eastern Alpine Conifer Chronology

(Nicolussi et al., 2009) which covers the last 9111 years and consists of samples originating from higher elevations in the Eastern Alps.

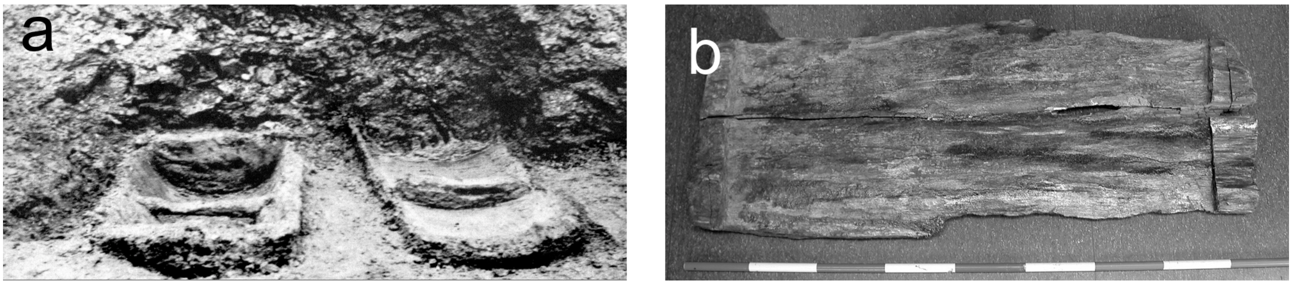

Figure 4: a) The two troughs in situ (photo: R. Pittioni, 1968, p.71). The right one (kbm-1) is dendrochronologically dated. The last measured tree ring marks the year 1245 BC. b) The current state of the analysed trough (kbm-1, inventory number 1547, length = 174 cm) during documentation at the Institute of Geography (photo: T. Pichler, 2007).

Results and Outlook

The dominating species of the artefacts analysed dendrochronologically is spruce (*Picea abies*). Only few samples (n=3) such as the bottom part of the trough (Fig. 4) consist of fir timber (*Abies alba*). We think that the prehistoric miners had excellent skills of specific wood properties. They used the most appropriate ones among the wood species available for particular purposes. The wood of silver fir is not resistant to bio-deterioration, but it is well suited for water constructions.

Up to now we have been able to crossdate the tree-ring series of 25 wooden objects, which resulted in a tree-ring record spanning 153 years. These dendrochronologically analysed wooden objects date back to the early Late Bronze Age (Fig. 5). The last measured tree ring of the site chronology dates back into 1237 BC. Five samples showed well preserved wane. Three of these samples indicate felling activity outside the growing period. In detail: One sample (kbba-13) arising from the prehistoric forest show a felling date autumn/winter 1257/56 BC. The felling date in autumn/winter 1243/42 BC of the other two samples (Fig. 3c+d) found at a small place some meters off Scheidehalde 50 is in good agreement. Furthermore, the established TRW-series are highly congruent with each other suggesting that both woodchip samples derive from the same trunk. All in all the tree-ring series associated to these samples including the outermost ring vary over a time span of two decades. Therewith mining activities on the site Kelchalm may be suggested for at least the time span between 1257 and 1237 BC.

According to the results of this study it can be stated:

i) The copper ore deposits in the Kelchalm region attracted already prehistoric men. Dendrochronological dating results reveal mining activities at this site of at least two decades. Furthermore, the accurate dendro-result dates the Bronze Age mining activities at the Kelchalm to about two centuries earlier than previous assumptions proposed by Richard Pittioni.

ii) The species of the investigated samples is mainly spruce. In few cases the prehistoric miners used the wood of fir because of its appropriate properties under wet conditions.

The dendrochronological analysis of the timber from the Kelchalm mine contributes new data to the chronological development of prehistoric mining in the Eastern Alps. Further studies and results from this mining area and others in the central Eastern Alps are expected.

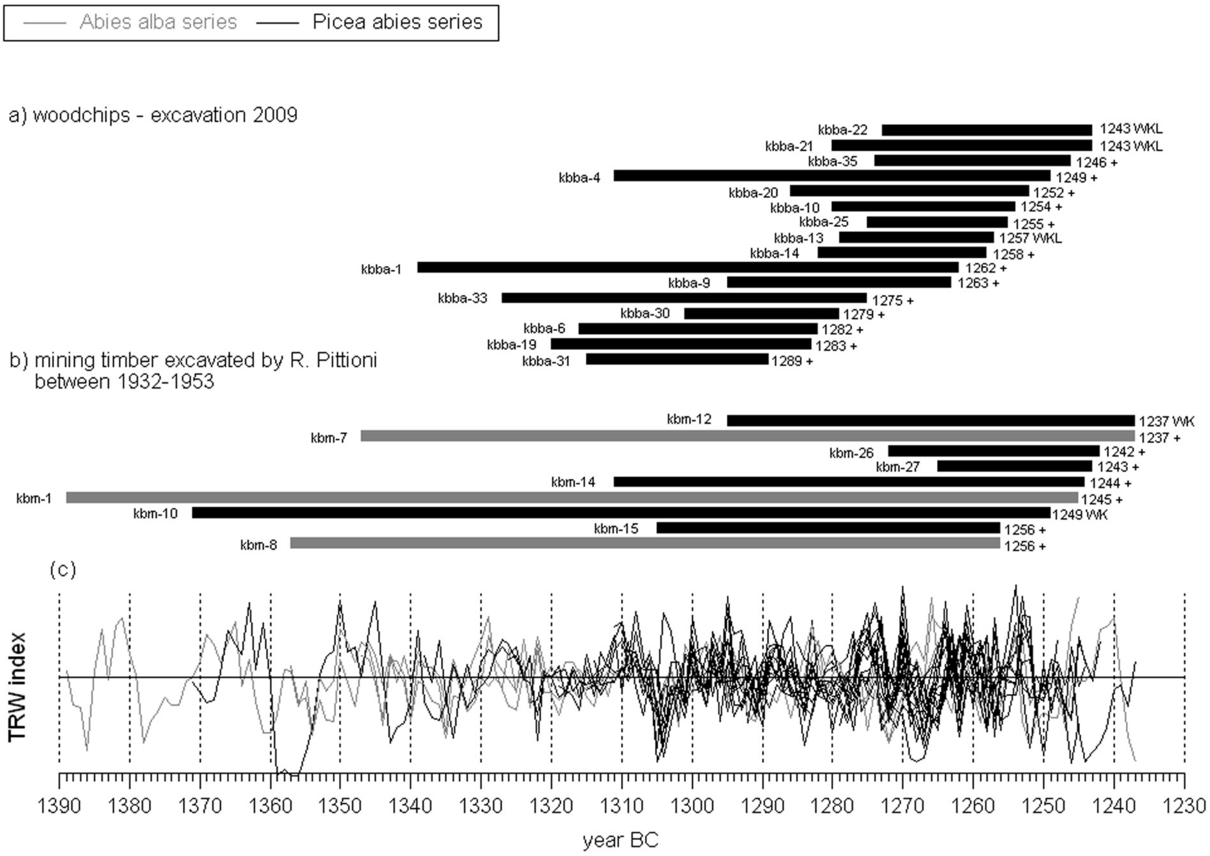

Figure 5: The dendrochronologically dated woodchips (a) excavated during summer 2009 and the wooden artefacts (b) excavated 1932-1953 from the copper mining site Kelchalm: Each bar represents a sample. The length of the bars indicates the length of tree-ring series obtained from the samples. Tree species, sample code, and calendar year of the last ring measured of each series is shown. WKL: terminal ring, logging following autumn/winter; WK: terminal ring present but latewood or earlywood not distinguishable; +: no terminal ring. (c) Synchronised tree-ring series of the dated samples.

Acknowledgements

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Archaeological quality of dendrochronological data

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This article is a methodical extract of my M.A. thesis, that will be published in „Leipziger Forschungen zur Ur- und Frühgeschichtlichen Archäologie“ soon.

Dendrochronology is the best way for chronometric dating in archaeology. Notably for specific archaeological periods, like the Iron Age, dendrochronological data have a special relevance, because, the method of C14- dating cannot be used here. On the one hand the data could be imprecise concerning the so called “Hallstattplateau” and on the other hand the span of these dates is too wide in order to correlate them with the defined archaeological periods.

Recently in my M.A. thesis I did not only discuss the current research of the late iron age, but also the general question how archaeologists should handle dendrochronological data. Like excavation results the data depends on interpretation and has to be observed critically. Data acquisition as well as information of Dendrochronologists about uncertainties concerning the results cannot be ignored. Unfortunately this is often impossible, because in archaeological publications the information about the dendrochronological results are mostly reduced to the date itself. Additional information like the number of year rings, tree species or the existence of the waney edge, are necessary to gain an understanding of the process of data acquisition and most important to get information about the exactness of the results. The question is how to use dendrochronological data wisely for archaeological contexts when it’s hard to distinguish facts from interpretation. Archaeological models can collapse, if they don’t have a solid database.

Preliminary remarks

I analysed dendrochronological data published in archaeological journals. As a first step a model was developed to evaluate the quality of the publication which based on the dendrochronological information of the articles.

Secondly dendrochronological data were selected to analyse the quality of the sampled object itself. The aim was to show how far a dendrochronological date is useable for archaeological purposes. As a third step the archaeological relevance of dendrochronological dates was questioned. In a case study the relation between the quality of the dendrochronological date and the archaeological significance were tested.

The late Iron Age or more precisely the Latène-Culture (approx. 475-15 BC) provides the temporal frame of the study. The Latène-Culture spread between France and Hungary, but in my thesis I had to limit my research to the German federal states of Bavaria, Baden-Württemberg and Rhineland-Palatinate and some parts of Austria and Switzerland (Fig. 1).

The primary source of the study are dendrochronological data from archaeological journals of these federal states and countries as well as supraregional periodicals, published between 1960 and 2007 (Tab. 1). Thirty-six dendrochronlogical dates from twenty-four archaeological sites were collected. These sites are structured in a data catalogue.

The structure of this catalogue consists of the following categories: the dendrochronological date, the archaeological site, information about the archaeological context, information about finds, dendrochronological laboratory, literature and quality of publication.

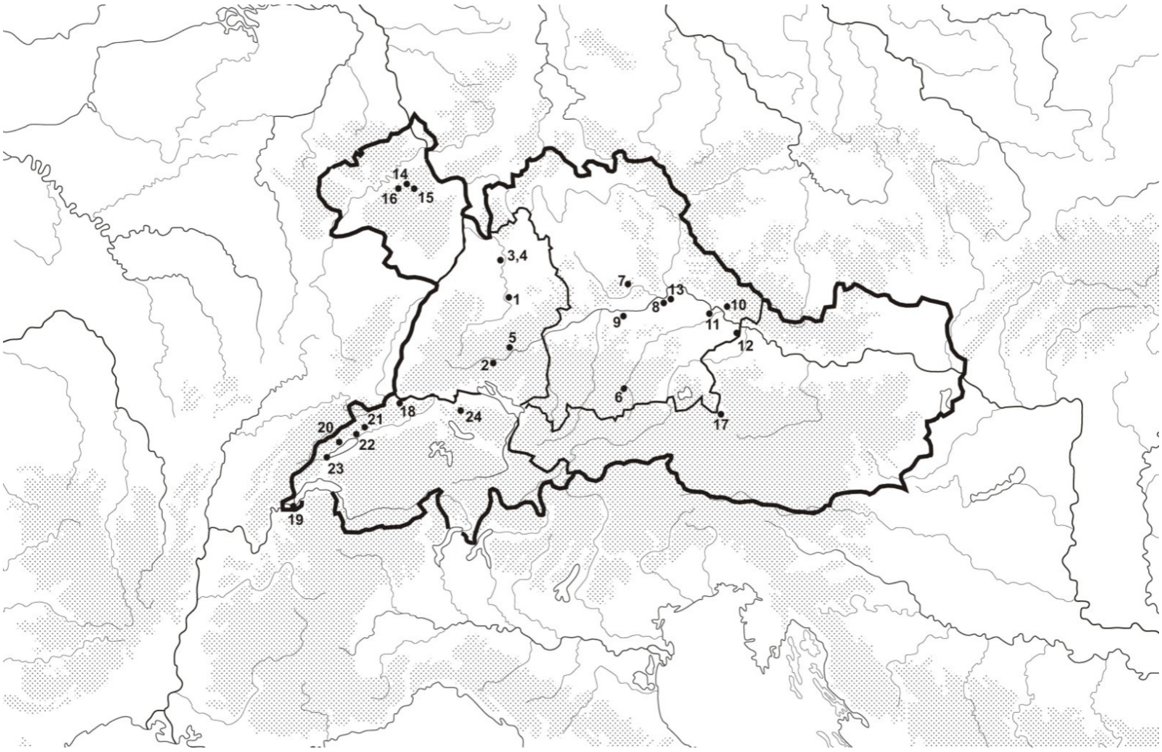

Figure 1: Archaeological sites: 1 Fellbach-Schmiden. 2 Mengen. 3 Nordheim-Kupferschmied. 4 Nordheim-Bruchhöhe. 5 Riedlingen. 6 Germering. 7 Greding. 8 Langquaid. 9 Manching. 10 Otzing. 11 Pankofen. 12 Hartkirchen. 13 Schierling. 14 Bundenbach. 15 Kirnsulzbach. 16 Wederath. 17 Dürrnberg-Hallersbichl. 18 Basel. 19 Genf. 20 Bevaix. 21 Cornaux. 22 La Tène. 23 Yverdon. 24 Oberwinterthur.

Table 1: List of archaeological journals used, sorted by regions.

Region	**Archaeological Journals**
South-Germany	- Archäologische Ausgrabungen in Baden-Württemberg - Fundberichte aus Baden-Württemberg - Das Archäologische Jahr in Bayern - Archäologie im Rheinland
Austria	- Archaeologia Austriaca - Archäologie Österreichs - Fundberichte aus Österreich
Switzerland	- Archäologie der Schweiz - Jahrbuch Archäologie Schweiz - Zeitschrift für Schweizerische Archäologie und Kunstgeschichte
Supraregional	- Archäologisches Korrespondenzblatt - Germania - Nachrichtenblatt Arbeitskreis Unterwasserarchäologie - Prähistorische Zeitschrift

Quality of Publications

Based on the information from of the articles five criteria for evaluation were developed:

1. The tree species: here information about the wood used for producing the object is provided.
2. The type of year ring: this criterion gives information about the preservation of heartwood, heartwood and sapwood or additionally the waney edge.
3. The number of year rings: this category provides information about the measured number of the preserved year rings and accordingly how many years the tree-ring-curve consists of, if more than one object was used for dating.
4. The number of samples: the criterion shows, how many samples are taken from the object or feature. The number of recovered objects differs from the number of samples, because not every object has to be sampled, but an object can be sampled more than one time.

5. The classification of the excavation: this fact can give information about the circumstances of the excavation. The differentiation between a rescue or research excavation could be useful as it can have positive or negative influence on the quality of the dendrochronological results (recovery-information).

For every criterion the articles were screened, if there are corresponding information. The points are divided in a binary way: „1 = present“ and „0 = non present “. Based on this model of evaluation five ranking groups arose. In the first group (one point) are all dates from articles with information about only one of the criteria. In the fifth group (five points) are all dates from articles with information about all of the criteria. An overview of the distribution of all five ranking groups is given in table 2.

Table 2: Ranking groups 1-5.The Sum column equals the group rank.

Archaeological Site	Dendrochronological Date	∑ Sum
Fellbach-Schmiden, BW, FRG	123 v. Chr.	5
Riedlingen, BW, FRG	177 v. Chr.	5
Riedlingen, BW, FRG	181 +/- 10 v. Chr.	5
Germering, BY, FRG	131 v. Chr.	5
Bevaix, NE, CH	39 v. Chr.	5
La Téne, NE, CH	225 v. Chr.	5
La Téne, NE, CH	38 v. Chr.	5
Nordheim-Kupferschmied, BW, FRG	193 +/- w. J. v. Chr.	4
Langquaid, BY, FRG	166 +/- 10 v. Chr.	4
Langquaid, BY, FRG	158 +/- 10 v. Chr.	4
Platting-Pankofen, BY, FRG	74 v. Chr.	4
Platting-Pankofen, BY, FRG	91 +/-5 v. Chr.	4
Bundenbach, RP, FRG	78 v. Chr.	4
Kirnsulzbach, RP, FRG	514 v. Chr.	4
Dürrnberg, SB, AT	516 v. Chr.	4
Dürrnberg, SB, AT	464 v. Chr.	4
Thielle/Cornaux, NE, CH	120 v. Chr.	4
Thielle/Cornaux, NE, CH	116 v. Chr.	4
La Téne, NE, CH	254 +/-8 v. Chr.	4
Nordheim-Bruchhöhe, BW, FRG	160 +/- 10 v. Chr.	3
Greding, BY, FRG	261 v. Chr.	3
Manching, BY, FRG	105 +/- 6 v. Chr.	3
Platting-Pankofen, BY, FRG	156 +/- 5 v. Chr.	3
Pocking- Hartkirchen, BY, FRG	51 +/- 10 v. Chr.	3
Schierling, BY, FRG	109 v. Chr.	3
Basel, BS, CH	36 v. Chr.	3
(Ober)Winterthur/Vitudurum, ZH, CH	158 v. Chr.	3
Otzing, BY, FRG	154 v. Chr.	2
Wederath, RP, FRG	208 v. Chr.	2
Genf, GE, CH	123 v. Chr.	2
Genf, GE, CH	80 v. Chr.	2
Yverdon-les-Bains, VD, CH	68 v. Chr.	2
Yverdon-les-Bains, VD, CH	161-158 v. Chr.	2
Yverdon-les-Bains, VD, CH	173/172 v. Chr.	2
Mengen, BW, FRG	180 v. Chr.	1

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Dendrochronological Quality

The quality of publication clarifies an important point: The ranking of the quality of publications is not the same as the archaeological quality of a dendrochronological date. That means, important archaeological dates could also be located in lower groups. The ranking of quality of publications just shows, how much information about the matrix of a dendrochronological date is available for archaeologists.

The analysis of the dendrochronological quality was continued with group 5. Only in this group all necessary information are available, which allows the archaeologist to make his own opinion about a date.

This second model of evaluation was directed at the characteristics of the wooden object itself. The definitions of each criteria were taken from current literature (e.g. Eckstein/Wrobel 2008). Table 3 shows the different distribution of points.

Table 3: Distribution of points per information to determinate the dendrochronological quality.

Points: → **Information:↓**	**1**	**2**	**3**
Tree species	Pine (P)	Fir/Spruce (F/Sp)	Oak (O)
Type of year ring	pure heartwood (H)	heartwood & sapwood (H/S)	waney edge (W)
Number of year rings	1 - 39	40 - 69	≥ 70
Number of samples	1	2 - 4	≥ 5

The points are divided in three parts, whose subitems are explained as follows:

1. The tree species was evaluated in an ascending order in correlation to availability of the tree-ring-curve and accordingly the dendrochronological comparative material.
2. Points for the type of year rings were assigned depending on the preservation of the pure heartwood, heartwood and sapwood or the preservation of waney edge. Only in this case exact information about the time when the tree was felled are available.
3. The number of year rings was divided in three parts, which were taken from the current literature (e.g. Cichocki 1998/99, Consciense/Gross 2001). The more year rings are available the better is the chance to match a year ring curve in a master curve.
4. The number of samples was included, because you can get additional information, if an object or a feature is sampled more than one time.

Table 4 illustrates the result of this evaluation. It shows the different distributions of points in a down ward order. The sum column shows clearly that all dates are closed to each other, but there are differences between the dendrochronological qualities.

Table 4 illustrates the distribution of points of these criteria in group 5.

Archaeological Site	Dendro-chronological Date	Tree species O/F/Sp/P	Type of year ring: H/S/W	Number of year rings	Number of Samples	∑ Sum
Fellbach-Schmiden, BW, FRG	123 BC	3	3	3	3	12
Germering, BY, FRG	131 BC	3	3	2	3	11
Bevaix, NE, CH	39 BC	3	3	3	2	11
Riedlingen, BW, FRG	177 BC	3	1	3	3	10
Riedlingen, BW, FRG	181 ± 10 BC	3	2	3	2	10
La Tène, NE, CH	225 BC	3	2	3	2	10
La Tène, NE, CH	38 BC	3	3	3	1	10

Archaeological Relevance

The date with the best dendrochronological quality is from a well of the square ditched enclosure of Fellbach-Schmiden in Baden-Württemberg (Fig. 2 (Nr. 2)).
The date of 123 BC is one of the most famous dates in the Late Iron Age and the whole archaeology. Therewith a lot of archaeological types of finds were dated after that and actually a complete archaeological period. That's why this case study was chosen to discuss the archaeological relevance.
Every archaeological context was checked, where this date was used. Thereby the dendrochronological date was related to the stratigraphy of the corpus of finds as well as to the arguments about the construction and destruction of the square ditched enclosure.
It became apparent, that the archaeological benefit of this famous date is extremely limited if nonexistent. The only definite conclusion from the Fellbach-Schmiden-date is the year, the oak was felled and thus the year the well was constructed. This date is just a *"terminus post quem"* for the archaeological objects, which were found in the well shaft; and therefor the moment they fell into or were deposited in the well. All objects could have been in use for decades at this moment, or they could have been made decades after the well sinking.
This shows clearly, that the ranking of the dendrochronological quality is not the same as the archaeological quality of a dendrochronological date, and the archaeological information content rises not proportional to the dendrochronological quality.

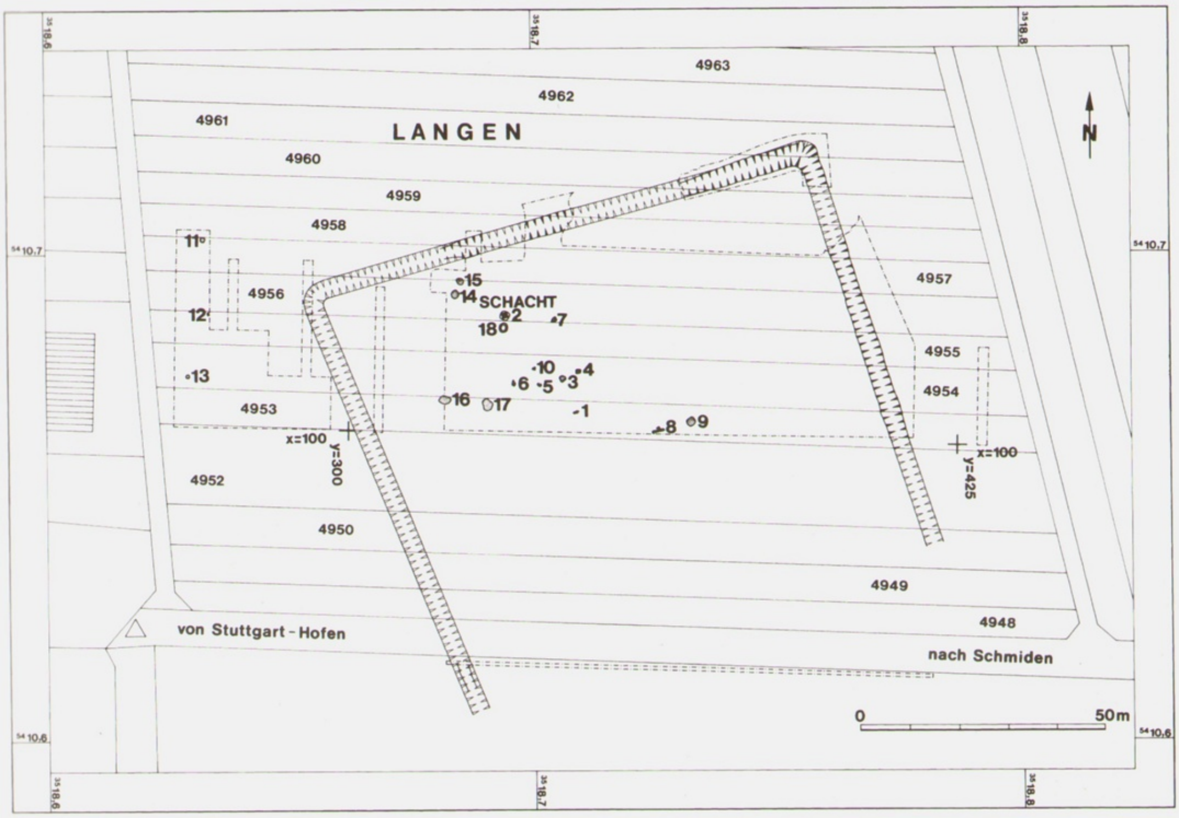

Figure 2: Excavation plan of the square ditched enclosure of Fellbach-Schmiden. Nr. 2 marks the well (Wieland 1999, 15).

Result

It was pointed out, that most of the analysed dates miss important information about their dendrochronological examination; information, which are necessary to guarantee transparency. It would be very useful, if archaeologists would keep to a special guideline when publishing dendrochronological data. Guidelines, for example like presented here.

Also became obvious, that it is essential to verify the quality of dendrochronological data. On the one hand the information of the object itself have to be checked to evaluate, how reliable a date is and weather it can be used for further archaeological questions. On the other hand the archaeological relevance has to be observed critically as well. The case study of Fellbach-Schmiden clarified, that archaeologists often use dendrochronological data for dating objects within features, for which they are clearly unsuitable.

List of abbreviations

AT - Austria
BS - Basel
BW - Baden-Württemberg
BY - Bavaria
CH - Switzerland
F - Fir
FRG - Federal Republic of Germany
GE - Geneva
H - Heartwood
NE - Neuchâtel
O - Oak
P - Pine
RP - Rhineland-Palatinate
S - Sapwood
SB - Salzburg
Sp - Spruce
VD - Vaud
W - Waney edge
ZH - Zürich

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The author thanks Prof. Dr. Sabine Rieckhoff (Institut für Ur -und Frühgeschichte, Universität Leipzig) for her helpful suggestions and her support. I am also indebted to Dr. Thomas Frank (Universität zu Köln) for his interest, encouragement and intercession to the TRACE-Organisation.

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SECTION 4

CLIMATOLOGY

Climate signals in width, density, $\delta^{13}C$ and $\delta^{18}O$ tree-ring series at two Iberian sites.

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Introduction

Tree-rings proxy based climate reconstructions have largely proven to be an accurate assessment of past climate variations at local, regional and hemispheric scales. For this purpose, the characterization of the influence of climate on tree growth is a necessary and crucial step. Sensitive trees would record the climate variable and period that limit their annual growth and this information is then used to reconstruct climate based on tree-ring proxies (Fritts 1976). The existing reconstructions based on tree rings are dominated by temperature signals. The reason is because dendroclimatological studies are usually conducted in high altitudes or high latitudes, where long-lived individuals can be found more easily because of the lower anthropogenic pressure and where harsh conditions shape very sensitive trees.

Existent literature reports that, in general terms, species growing under temperate climate response positively to summer warmth (Etien *et al.* 2008; Büntgen *et al.* 2006, 2008) since precipitation is generally not a limitation whereas cold temperatures stops cell division and development in the trunk (Rossi *et al.* 2003). On the other hand, species living under Mediterranean climate are usually described to depend on moisture availability (Touchan *et al.* 2005, 2007, 2008a). This often leads in combination with temperature effects to a drought sensitivity signal (Esper *et al.* 2007, Nicault *et al.* 2008; Touchan *et al.* 2008b, 2010).

The Iberian Peninsula has a predominant Mediterranean climate which is characterized by cool temperatures in winter and dry and hot summers. In addition, there is high spatial and temporal variability in precipitation (Rodríguez-Puebla et al. 1998) and ecosystems dynamics are basically controlled by moisture availability (Piñol *et al.* 1998). Previous work on the climate-growth relationship at high altitudes in this area reports a sensitivity mainly to temperature in the northern part (Pyrenees, Tardiff *et al*. 2003, Andreu *et al*. 2007, Büntgen *et al.* 2007) which loses its positive influence on tree growth towards the south but, in turn, no clear influence of precipitation is found (Parque Natural de Sierra de Cazorla, Martin Benito *et al.* 2008). Except for the Pyrenees area, tree-ring climate relationships in the Iberian Peninsula are still rather unclear and dendroclimatological investigations in old forests to assess their potential for climate reconstructions are scarce. Moreover, the usefulness of proxies such as tree-ring stable isotopes has barely been explored.

With the aim of assessing the strength of the climatic signal in each tree-ring record and thus, their potential for climatic reconstructions, we analyze the climatic significance of several tree-ring series from two pine-species stands growing at high elevations in the Iberian Peninsula: Pyrenees and South of Spain.

Six tree-ring variables were used: tree-ring width (TRW), earlywood width (EWw) and latewood width (LWw), maximum latewood density (MXD), stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes.

Material and Methods

The two study sites are *Parc Natural del Cadí-Moixeró* (UPF) located in the Pre-Pyrenees and *Parque Natural Sierra de Cazorla, Segura y las Villas* (NCZ) in the South of Spain. Both locations are under the influence of Mediterranean climate (Fig. 1): the UPF site is on the transitional boundary from Mediterranean to Eurosiberian climatic regions and the NCZ site is characterized by a typical high elevation Mediterranean climate. The pine species sampled at UPF was *Pinus uncinata* Ramond ex DC. in Lam. et DC and at NCZ *Pinus nigra* Arn. spp. *salzmannii* var. *salzmannii* (Dunal).

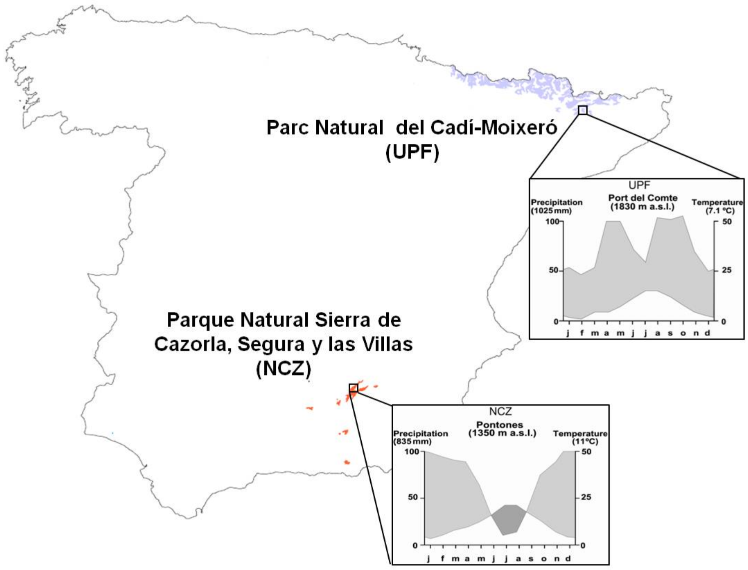

Figure 1: Location of the two study sites and their climate diagrams. The shaded areas indicate coverage of P. uncinata and P.nigra, respectively

Sampling was carried out during summer of 2006. Cores were taken with an increment borer and preparation and analysis followed dendrochronological procedures described by Stokes and Smiley (1968). Ring widths (TRW) were measured on 89 series at NCZ and 75 at UPF. The accuracy of the cross-dating and measurements were verified using the computer program COFECHA (Holmes 1983).

From the set of cores, 32 and 28 samples were selected for density analysis at NCZ and UPF respectively. Lathes perpendicular to the wood fibres were extracted from the cores and analyzed following X-ray microdensitometric techniques developed by Polge (1965). As results, series of measurements of earlywood width (EWw), latewood width (LWw) and maximum density (MXD) were obtained.

Standard dendrochronological techniques were used for chronology developments (Fritts 1976, Cook and Kairiukstis 1990). For each proxy and site, chronologies were built with TurboArstan®. Individual series were standardized to remove trends in the mean but preserving multi-decadal scale wavelengths by fitting a negative exponential curve or cubic smoothing spline of 67% of the series length with a 50% frequency response cut-off to the raw series. Chronologies based on the different variables were built by using a bi-weight robust mean to reduce bias caused by extreme values.

In general, stable isotope chronologies require fewer trees to provide a representative average series for a site and 10 cores were selected at each site for stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope individual analysis. Tree rings were split manually with a scalpel under a stereomicroscope and then α-cellulose was extracted. The $^{13}C/^{12}C$ isotope ratios were measured as CO_2 by combusting the α-cellulose samples in an elemental analyzer (Fisons NA 1500NC). Similarly, oxygen isotopes were measured on CO utilizing a TC/EA pyrolysis furnace. The isotope ratios are given in the conventional delta (δ) notation, relative to the standards VPDB ($\delta^{13}C$) and VSMOW ($\delta^{18}O$).

We applied the atmospheric correction to the $\delta^{13}C$ series because of the decreasing trend of atmospheric CO_2 signature from increasing fossil fuel burning since the industrialisation (see details and values at McCarroll and Loader 2004). After the correction of the stable carbon isotope measurements, individual series of $\delta^{13}C$ and $\delta^{18}O$ were z-transformed and averaged to build the final chronologies.

Homogenized mean monthly temperatures (T) and total monthly precipitation (P) were available from nearby stations. The influence of climate on each tree-ring variable was investigated by computing simple linear correlations (*r*) with monthly climate variables from July of the year previous to growth (*t-1*) to October of the current year (*t*).

Results and Discussion

At the pre-Pyrenees site UPF, all tree-ring width variables are affected positively by previous autumn (October-November) temperatures (Fig. 2), as has already been reported by Gutiérrez (1991), Tardiff *et al.* (2003), Büntgen *et al.* (2007) and Andreu *et al.* (2008). In temperature controlled environments such as UPF with enough moisture available to the trees, higher temperatures in autumn can favour net photosynthesis and increase food storage that will be available for next year's growth (Fritts 1976). Consequently, cold temperatures in autumn are likely to limit the formation of metabolic reserves and affect radial growth in the following year. We could also identify significant influences of the current year's temperatures on growth similar to those described by Tardiff *et al.* (2003) (May temperature) or Büntgen *et al.* (2007) (late spring to summer temperatures). For instance, TRW respond positively to March to June temperatures, EWw to April, June, September and October and LWw to the very early year temperatures (January to May). Similarly, MXD is discontinuously affected by temperature from early spring to summer (February, May, and September) and stable isotopes also show high and positive correlations with spring to summer ($\delta^{18}O$) and late summer ($\delta^{13}C$) temperatures of the year of growth. Thus, at UPF tree growth is controlled by temperature during the growing season since warm conditions allows stems cell division and differentiation. Actually, growing season temperature (May to September) has already been reconstructed at the Pyrenees based on TRW width and MXD records by Büntgen *et al.* (2008, 2010).

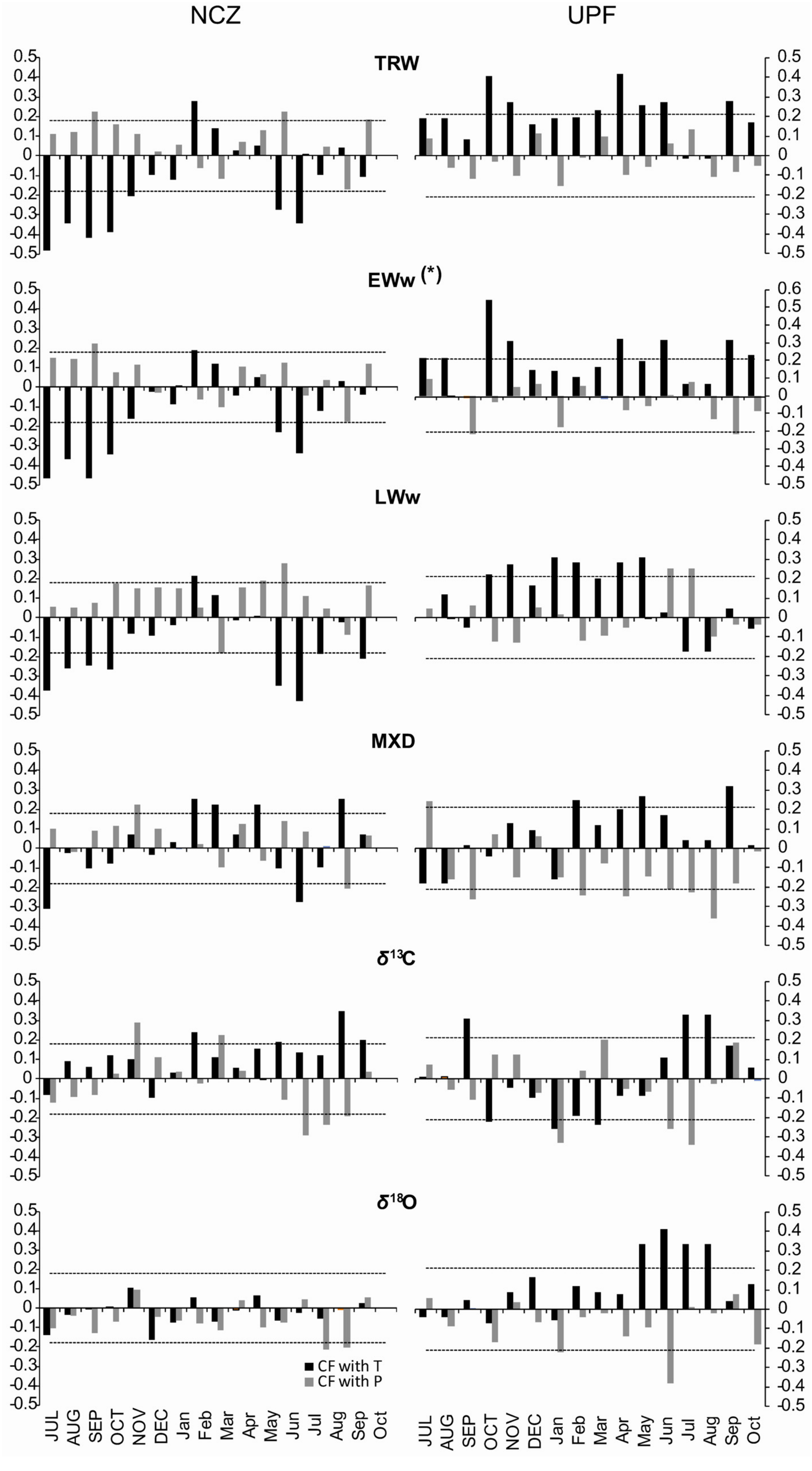

Figure 2: Monthly correlation coefficients between climate and tree-ring proxies from Cazorla (NCZ) and Pedraforca (UPF) for the period July of the previous year (t-1) to October of the current year (t). Grey bars indicate correlation with precipitation and black bars with temperature. Abreviations: Total ring width (TRW); early-wood width (EWw); late-wood width (LWw); maximum density (MXD), stable carbon isotope ratios (δ^{13}C) and stable oxygen isotope ratios. Dashed lines indicate 95% significance level.(*) Notice different scale.

Precipitation signals are not as consistent across different tree-ring variables as the temperature signals. This is expected in an alpine climate where enough moisture is available throughout the whole year and the proximity of UPF to Mediterranean Sea favours a higher amount of precipitation during summer. Nevertheless, LWw show a slight positive influence of summer precipitation; while MXD, δ^{13}C and δ^{18}O display negative summer precipitation signals. Precipitation does not seem to be a limiting factor for tree-growth, but its availability during summer can prolong the growing season thereby increasing LWw but decreasing MXD, since wetter conditions favour wider lumen sizes and thinner cell walls (Larson, 1994).

Besides, high summer temperatures promote high evapotranspiration rates which increases when rainfall occurs and result in lower tree-ring δ^{13}C (Farquhar *et al.* 1982; Leavitt and Long, 1989; Saurer *et al.* 2008).

The δ^{18}O-climate relations found at UPF are consistent with earlier reports from the Swiss Alps (Saurer *et al.* 2008; Battipaglia *et al*. 2009) and they are also in accordance with regional patterns described by Treydte *et al.* (2007) for a European network of δ^{18}O. They found a common physiological response to summer conditions in temperate climates: low moisture combined with higher temperatures increases transpiration rates; which enhances leaf water enrichment resulting in higher δ^{18}O values.

At NCZ, the previous summer to autumn temperature exerts a negative influence on tree growth in *P. nigra* individuals which is consistent with reports of previous studies concerned with TRW, EWw and LWw at the Cazorla Range (Martin-Benito *et al.* 2008, Andreu *et al.* 2008). This negative influence of temperatures in combination with a positive influence of precipitation of the previous September on TRW and EWw suggests a strong dependency of the metabolic reserves from the previous year since warm late summers can prolong the growing season, limiting the number of photosynthates stored for next year's growth (Fritts 1976). High summer temperatures (June to July) during the year of growth also exert a negative influence on TRW, EWw and LWw probably as a consequence of the strategic stomata closure adopted in order to avoid xylem embolism due to the high transpiration rates. This may also limit tree production and the food storage for next year growing season would be reduced.

In general, the climate at NCZ is harsh (Fig 1), i.e., winters are very cold with absolute minimum temperatures that can be far below zero and often considerable snow fall occurs while in summer extreme maximum temperatures over 40ºC in the shade can be reached (Creus-Novau 1998). The combination of high temperatures and low rainfall amounts theoretically suggests that at NCZ summer droughts may occur. Consequently, a summer precipitation signal in the tree ring series would be expected. However, the dependency of tree growth on precipitation was surprisingly low at NCZ and no significant correlations were found with the Palmer Drought Severity Index (Palmer 1965) (results not shown). Previous studies analysing tree-ring width series from this region did not find a clear summer precipitation signal; we found a non significant positive effect of previous summer autumn precipitation on TRW and EWw. The mean total annual precipitation amount is 835 mm (Fig. 1), a relatively high value for the Mediterranean, which denotes a rather moist character of the climate. Indeed, NCZ is one of the highest rainfall zones in Spain, surrounded by typical low-moist areas from southeast of the Iberian Peninsula (Heywood 1961). Moisture levels are generally quite high throughout the year, so water may be still available to trees during the above-mentioned dry period of July-August. Additionally to the water storage in the soil profile, occasional summer thunderstorms and fogs that may appear anytime of the year (Creus-Novau 1998) can also contribute to the minimisation of the hydric stress on trees in summer.

Only δ^{13}C seems to record a certain degree of hydric stress in summer denoted by significant negative correlations with July, August and September rainfall. This is probably related to the increased stomatal closure under dry conditions which affects directly the isotope fractionation and results in a negative correlation between δ^{13}C and precipitation. In fact, negative correlations of δ^{13}C with summer precipitations have been reported for different pine species across the Iberian Peninsula (Andreu *et al.* 2008; Voltas *et al.* 2008), in the French Alps (Gagen *et al.* 2004; Gagen *et* *a.l.* 2006) with *Picea abies* (L.) Karst., in the Swiss Alps (Treydte *et al.* 2001) and for individuals of *Pinus sylvestris* L. in Finish Lapland (Gagen *et al.* 2007). This common summer precipitation signal of stable carbon isotopes ratios across different locations in Europe was already explored by Treydte *et al.* (2007).

Surprisingly MXD at NCZ did not show a consistent pattern of correlation with temperature, just a slight influence of some dispersed months during previous and current year of growth. Moreover, δ^{18}O did not display significant correlations with any of the climatic parameters although we expected some signal related to summer hydric stress since stable isotope ratios of oxygen in tree-ring cellulose have been demonstrated to correlate well with climatic factors such as temperature (McCarroll and Loader, 2004) and vapour pressure deficit (Ferrio and Voltas 2005).

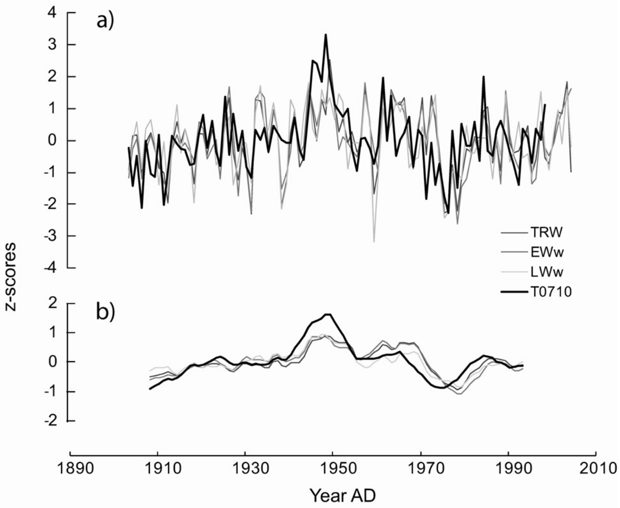

Figure 3: Comparison of NCZ tree-ring width chronologies and target temperature data. a) Inverse indices of TRW, EWw and LWw from NCZ and July to October temperature indices (T0710) of previous year (t-1). b) Medium to low frequencies highlighted by a 10-year moving average.

Both UPF and NCZ trees appear to be strongly dependent on lagged physiological effects caused by temperatures but with the difference that the effect exerted on tree ring variables is positive in the northern site (UPF) and negative in the southern site (NCZ). This opposed effect of temperature on tree-ring variables is consistent with the geographical pattern of temperature variation across the Iberian Peninsula. Temperature dynamics in the two different Mediterranean sites seem to play the key role, limiting tree growth by cold temperatures in the more temperate site of the pre-Pyrenees. Temperature response is reversed at the drier and hotter site NCZ, located at high elevations as well, but where tree growth is also limited by high summer temperatures.

The dependence on the temperature of the previous growing season, which is the clearest for ring-width related variables (TRW, EWw, LWw), is not only consistent at inter-annual but also at inter-decadal wavelengths (Figs. 3 and 4). At NCZ (Fig. 3), the climatic information recorded by all three variables is almost identical and agrees in the different frequency domains with the July to October temperature record of the previous year. At UPF (Fig. 4), the tree-ring proxy EWw best records October to December temperatures of the previous year. The comparison of the smoothed tree-ring and temperature records shows a generally better agreement at NCZ. The synchrony is remarkably high except for an offset during the 1940s, where tree rings did not record the magnitude of the increase in temperatures. This could be either due to local differences in the magnitude of the warmth between the sampling site and the location of the weather station, or to inability of the trees to react to such increased warmth. A test with regional climate data will help to answer such a question and to establish the potential suitability of the tree-ring proxies to reconstruct temperatures at both locations.

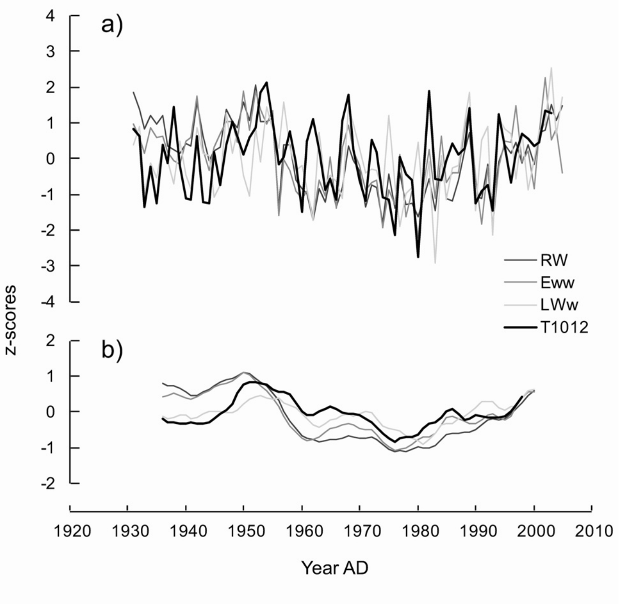

Figure 4. Comparison of UPF tree-ring width chronologies and target temperature data. a) TRW, EWw and LWw from UPF and October to December temperature indices (T1012) of previous year (t-1). b) Medium to low frequencies highlighted by a 10-year moving average.

Conclusions

At both sites a dominant temperature signal was found while the influence of precipitation was shown to be limited to the summer period, evidencing a slight drought stress. The significant temperature signals at UPF and NCZ are recorded at both inter-annual and inter-decadal timescales by TRW, EWw and LWw pointing out their potential for climate reconstructions.

Tree-ring stable isotopes provide additional information regarding the tree growth-climate relationship but further investigations are needed in order to clarify the absence of significant correlations with climate for some parameters, e.g., δ^{18}O at NCZ.

Acknowledgements

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Exploring climatic signals in stable isotopes of *Sclerocarya birrea* tree ring chronologies from the Sahel region in West Africa

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Introduction

The instrumental record of climate is just too short to understand how climate changes in Africa. Although a number of proxy data series have been developed from temperate and subtropical regions to trace the course of environmental and climatological fluctuations, precise palaeo-climate records from the tropics, notably from Africa, are still sorely lacking (Gebrekirstos 2009a). Therefore, it is central to identify potential climate proxies that could provide empirical data regarding past climatic events and its impact on important agroforestry species.

Tree ring widths and stable isotopes in tree rings have been successfully used as climate proxies in temperate regions. Recently some progress has been reported with regard to the potential of tree rings as climate proxy in semi-arid Africa (Gebrekirstos et al. 2009b, Gebrekirstos et al. 2011, Trouet et al. 2006, Fichtler et al. 2004, Wils et al. 2010). Gebrekirstos et al (2009b) demonstrated the potential of $\delta^{13}C$ in tree rings of Acacia species to reflect physiological responses to environmental and climate changes as a tool for paleoclimatic reconstructions in Ethiopia. High correlations (up to $r = -0.82$) were found between the $\delta^{13}C$ chronologies and precipitation data, which demonstrates their potential to reconstruct precipitation in semi-arid tropics. Wills et al (2010) also demonstrated the use of $\delta^{13}C$ in *Juniperus procera* by reconstructing the flow of the Blue Nile River.

In this context, we extend the study to West Africa in Burkina Faso (Sahel region) and East Africa in Tanzania (Miombo woodland). The overall purpose of the study is to establish large-scale correlation patterns between tree growth, precipitation and temperature that are affected by the Indian Summer Monsoon (ISM) and the West African Monsoon (WAM) in East and West Africa, respectively. This knowledge will help us to explore local and regional climate processes. In this paper we present preliminary pilot results that indicate the potential of stable oxygen and carbon isotopes in tree rings of *Sclerocarya birrea* from the Sahel region in Burkina Faso as a climate proxy.

Methodology

Study site and climate

Six samples of stem disks were collected from Sahel region in Burkina Faso (Tugure), (N13°22'17,5" W00°28'16,7") (Fig. 1). The rainfall distribution of the study region is uni-modal within a rainfall range of about 500 to 600 mm (Fig. 2). The rainy season starts in May and extends to September, with the wettest month in August. Mean annual temperature is 37 °C with the hottest months from March to May (about 40 °C). Burkina Faso has three major climate regimes, the Sahel in the north, the Sudan Guinea zone in the south and the Sudano Sahel in transition (Fig. 1). The Sahel zone climate is influenced by the Sahara desert and the WAM.

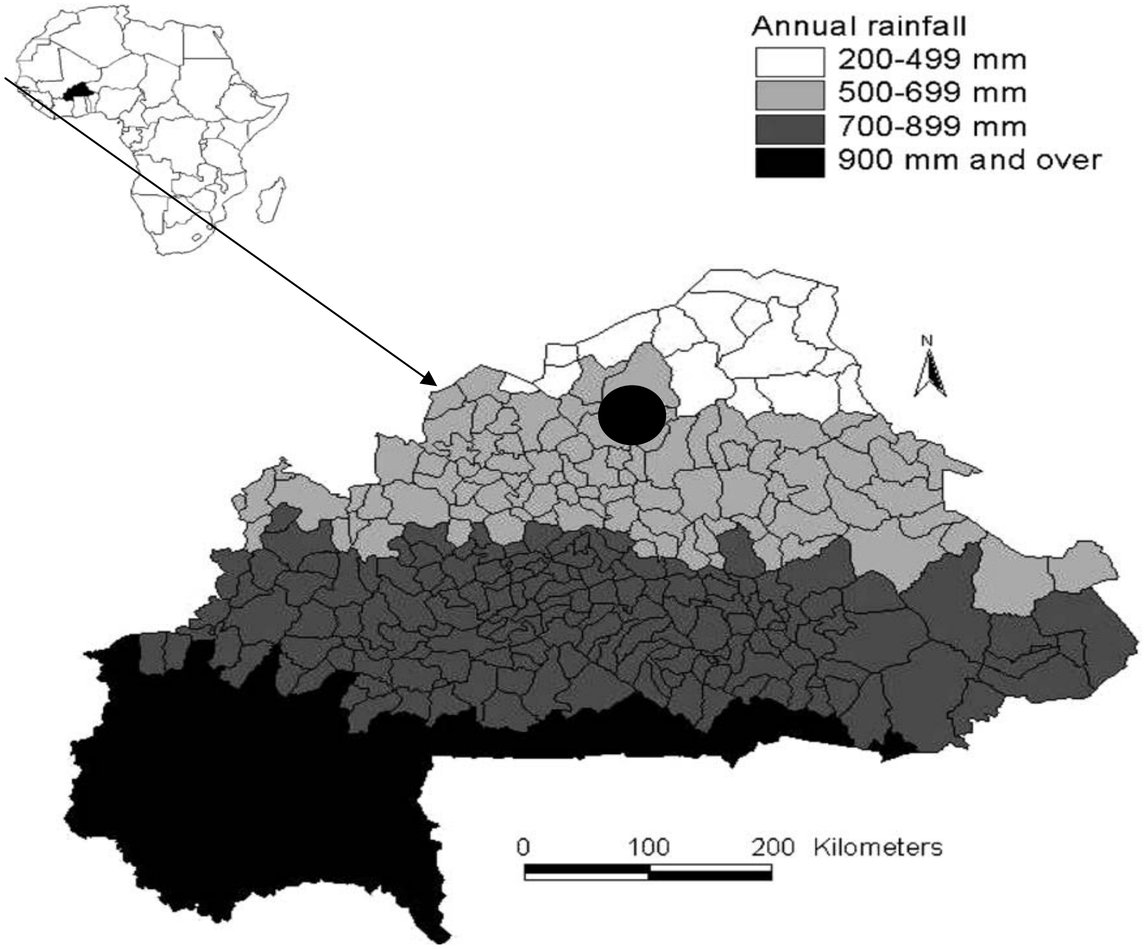

Figure 1: Location of the study area Burkina Faso in West Africa. The circle indicates the location of the study site (village Tugure)

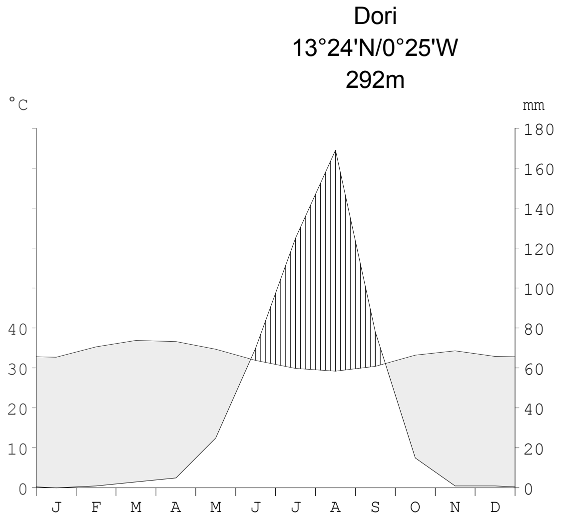

Figure 2: Climatic diagram from Dori station drawn according to Walter (1973). Rainfall (mm) and temperature (°C) data (1987–2007) were obtained from Burkina Faso Meteorological Agency.

Study species and measurement of stable isotopes

For the δ^{13}C and δ^{18} O pilot measurements, we selected two stem disks of *Sclerocarya birrea* that had been dated using standard dendrochronological procedures. *Sclerocarya birrea,* a deciduous tree that belongs to the family Anacardiaceae, is found in most parts of Africa. It grows to a height of about 20 m.The δ^{13}C and δ^{18} O analyses were performed for each individual at one-year resolution from 1983 to 2007. Powdered samples were produced from two to three radii of each tree using a drill width of 0.5 mm (Fig. 3b). The powders were pooled into tin capsules and homogenized with a metal stick to represent the whole ring. The disk was cleaned with compressed air after collecting each sample to avoid cross contamination. We used bulk wood for this investigation. From each sample, 1 mg and 0.2 mg of powdered wood was used for the δ^{13}C and δ^{18} O measurements, respectively. This was carried out at the Center for Stable Isotope research and Analysis, Forest Ecosystem Research, University of Gottingen, Germany.

The trend in δ^{13}C series related to the decline in atmospheric δ^{13}C values was removed following the method described in Mc Carroll & Loader (2004). To determine the relation between the δ^{13}C and δ^{18} O values and climate variables, we used precipitation (monthly and annual), Palmer Drought Sensitivity Index (PDSI), mean relative humidity, sun shine hours, maximum temperature and evapo-transpiration. The climatic data were obtained from Burkina Faso Metrological Agency, except for PDSI data which we obtained from Dai et al. (2004). We used the climatic data from Dori station, which is the closest available station to our study site. STATISTICA for windows (Version 6.0) was used as a tool for the data analyses. Unless stated otherwise, results are statistically significant at $P<0.05$.

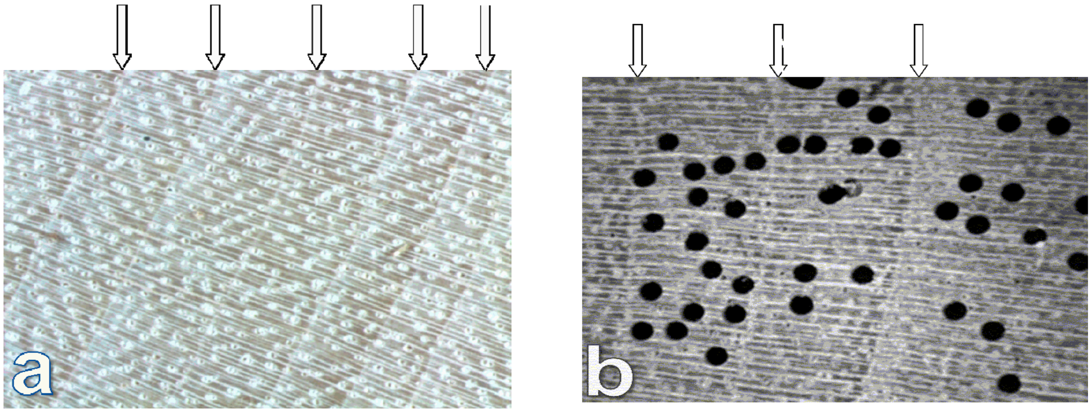

Figure 3: Cross-sections of Sclerocarya birrea a) arrows indicate annual growth boundaries b) method of sample preparation. Black dots represent holes drilled for obtaining wood material for stable isotope analyses.

Results and Discussion

Formation of growth boundaries

This pilot study explores the formation of growth boundaries and potential of stable isotopes in tree rings of *S. birrea* for climate reconstruction in the Sahel region. *S. birrea* forms very distinct rings characterized by marginal parenchyma bands, which run around the entire stem disc (Fig. 3a). This is in agreement to the phenology of *S. birrea,* which is a drought deciduous species that sheds its leaves during the dry season. The study area is marked by uni-modal rainfall distribution and about eight months of dry season that triggers formation of annual growth boundaries. Compared to the drought deciduous *Acacia* species in Ethiopia (Gebrekirstos et al 2008), ring formation in *S. birrea* is very distinct.

Inter annual δ^{13}C and δ^{18} O variations

The preliminary results showed that the inter-annual patterns of δ^{13}C and δ^{18} O ratios in tree rings of *S. birrea* are uniform between the two individual trees indicating that marked fluctuations in stable isotope ratios are synchronous. This is further confirmed by cross-correlation analyses of the species mean δ^{13}C series ($r = 0.42$) and δ^{18} O ($r = 0.62$). The δ^{13}C and δ^{18} O values range from -24.6‰ to -26.7‰ and 21.24‰ to 25.45‰, respectively. However it is worth noting that the statistical correlations we mentioned in the following are still preliminary and might change as a result of increasing sample length and depth in the future.

$\delta^{13}C$ and δ^{18} O mean values also showed similar variation patterns and significant positive correlations (r = 0.53). The similar pattern within and between $\delta^{13}C$ and δ^{18} O ratios indicate that external factors affected isotope fractionations in a similar way.

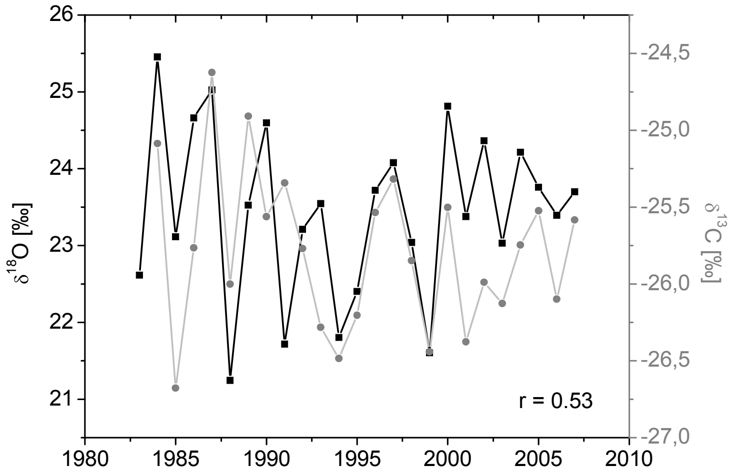

Figure 4: Sclerocarya birrea $\delta^{13}C$ and $\delta^{18}O$ patterns and correlations

$\delta^{13}C$, δ^{18} O and climate

Sclerocarya birrea responded to the short rains that normally started around May and showed significant correlations to the rainy season (July-September). In general, both $\delta^{13}C$ and δ^{18} O showed negative correlations with rainfall, humidity and PDSI. In the contrary they showed positive correlations with sun shine hours, maximum temperature and evaporation. Furthermore, precipitation in August (the wettest month) proved to have a stronger influence on the $\delta^{13}C$ and $\delta^{18}O$ isotopic variations than annual precipitation.

Some of the relationships mentioned are explained by the covariance of some climatic factors, e.g. high rainfall would mean higher relative humidity and PDSI. Consequently, stomatal conductance would be enhanced that leads to the depletion of $\delta^{13}C$. In dry years moisture stress would lead to stomata closure and enrichment of the heavier isotopes (e.g. Gebrekirstos et al. 2009b, Wils et al 2010). Similarly, negative correlations with $\delta^{18}O$ also reflects that $\delta^{18}O$ in tree rings of *S. birrea* records dry and moist years. During drier conditions it will be harder for the heavier isotopes to evaporate and hence heavier concentration of $\delta^{18}O$ that indicated drought years. In contrast, depletion of the heavier isotope $\delta^{18}O$ indicates moist years. Treydte et al. (2010) reported that $\delta^{18}O$ in tree rings primarily record the source water information. Hence, the significant correlation of $\delta^{18}O$ with precipitation amount in the rainy season would also reflect that the main source of water for the growth of *S. birrea* is soil water.

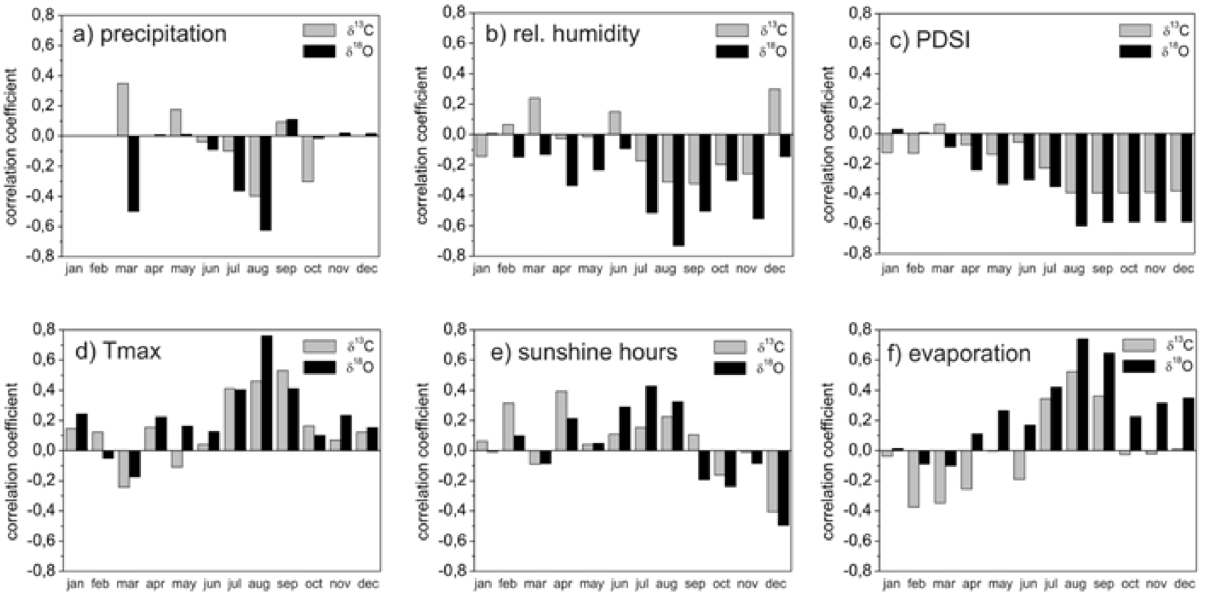

Figure 5: Correlation between Sclerocarya birrea $\delta^{13}C$ and $\delta^{18}O$ and climate parameters

Outlook

The pilot measurements showed the potential of stable isotopes in tree rings of *S. birrea* as climate proxy. The oldest tree we found in Tugure (the present study site) is about 130 years. Our ultimate objectives are 1) to develop longer tree ring chronology from different agro- ecological zones influenced by different climate regimes to put the short instrumental record including the Sahel drought events into a longer perspective. 2) to investigate the impact of climate variability on the growth and water use of the species in the face of climate changes.

Acknowledgments

We are grateful to BMZ and GTZ for funding the projects in Burkina Faso (ALUCCSA) and Tanzania (ReACCT). Our sincere thanks to Dr Jules Bayala and Jonas Koala for their help during the field work in Burkina Faso, and Reinhard Köpp for polishing the wood samples.

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$\delta^{13}C$ and δD in tree growth rings of *Pinus pinea* and its relationship with climate in Doñana National Park (Spain)

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Introduction

The Doñana National Park is one of the most important protected coastal areas in Europe (Serrano et al. 2006, Garcia Novo et al. 2007). This area (located in the southwestern Iberian Peninsula) is particularly sensitive to the consequences of Global Change such as increases in temperature and decrease in seasonal rainfall (IPCC 2007). This fact is noted in the Spanish Climate Change Report (2007) where an upward trend in temperatures of 1 to 2 degrees Celsius is reported over the period 1850 to 2005 and a change in rainfall patterns. The effects of this change have been notably severe in the southern Iberian Peninsula (IPCC 2007). In this context it is essential to study the response of the plants to climate change on regional scale. Stable isotopes are a powerful method to study water and carbon fluxes within an ecosystem (Resco et al. 2009) and specifically tree ring analysis offers a unique opportunity for understanding the response of trees to drought stress over decades, over centuries and millennia.

In Mediterranean regions, water is often a limiting factor for plant growth, due to high losses from the plant via evapotranspiration. However, an excess of water (such as in temporary ponds in Doñana National Park) can also cause physiological responses, similar to water stress and can cause stomatal closure (Kozlowski 1984, Ewe & Sternberg 2002). Thus, stomatal movement is an able mechanism that controls water loss from the leaves and optimizes carbon assimilation. Under stress situations (like higher air temperatures, lack or excess of water), the stomata close to avoid losing water and the CO_2 influx becomes scarce and Rubisco (the enzyme responsible for carbon fixation) reduces its discrimination against ^{13}C from the carbon dioxide within the intercellular spaces. This fact, affects to carbon isotopic composition of organic molecules (like glucose) formed during photosynthesis (e.g. Farquhar & Richards, 1984, Farquhar et al. 1989, Ehleringer & Dawson 1992, Saurer et al. 1997). Consequently, plants that have experienced water stress show less negative carbon isotopic values than non-stressed plants.

Hydrogen isotope ratios of stem cellulose of tree rings have been used to reconstruct relative humidity and rainfall patterns (Burk & Stuiver 1981, Yapp & Epstein 1982, Edwards et al. 1985, Edwards & Fritz, 1986). The hydrogen isotopic values in stem cellulose of tree rings preserve a signal related to the fractionation between source water and cellulose such as the isotopic signature of leaf or/and xylem water used to cellulose synthesis and the isotope composition of rainfall, which is mainly dependent of temperature (e.g. Sternberg et al. 1986, Rozanski et al. 1993). But hydrogen isotopes in tree rings are not a direct record of the isotopic composition of rainfall, since there are many steps along the path from source water to cellulose (Roden et al. 2000). For example, during evapotranspiration water molecules containing the lighter isotope are able to diffuse more rapidly than those that include the heavier isotope. The net effect is an enriched in δD values in plant material and vice versa (Roden & Ehleringer 1999b, Waterhouse et al. 2002). However, biochemical fractionations are not fully understood and can result in both enriched and depleted values of the isotope composition in organic molecules (Roden and Ehleringer, 1999b).

In this study we analyzed $\delta^{13}C$ and δD from *Pinus pinea* growth rings in the Doñana National Park to investigate the relationship between isotope variability associated to climate variability to obtain a better understanding of the physiological process underlying tree growth. Consequently, this test provides an indication of whether dendro-isotopes of carbon and hydrogen can be a good climate proxy in areas sensitive to the consequences of global change as Doñana National Park.

Material and methods

Description of study site

Doñana National Park lies between 36º 48´- 37º 08´ N and 6º 16´- 6º 34´ W (Fig. 1). This area is given the highest degree of environmental protection in Spain and it was designated as a Biosphere Reserve in 1980. This region is characterized by two main landscape types: marshland and aeolian sands. The marshes are a place of transit, breeding and wintering grounds for thousands of European and African birds, being the largest ecological reserve in Europe. The aeolian sands cover is composed of several dune generations originally deposited by marine material in the Holocene. Consequently, hundreds of small ponds appear in rainy years when the water table rises above the topographical surface.

The vegetation of Doñana National Park is dominated by Mediterranean scrubland such as *Cistus libanotis, Rosmarinus officinalis, Halimium commutatum, Erica scoparia, Erica ciliaris, Ulex minor, Cistus salvifolius*, being *Pinus pinea* the dominant tree species. The soil where the trees for this study lay is arenosols (FAO soil classification) and the average distance to water table is two meter.

Doñana has a Mediterranean climate with Atlantic influences, classified as dry sub-humid. The mean annual temperature is 18º-19ºC, the seasonal minimum temperature values are seen in winter, and the seasonal maximum values correspond to July with average values between 25 º-29 ºC. Average annual rainfall varies between 500-600mm. These values show a clear seasonal rainfall pattern, with the minimum in summer (June-September) and maximum in December with an occasional secondary maximum in April-May.

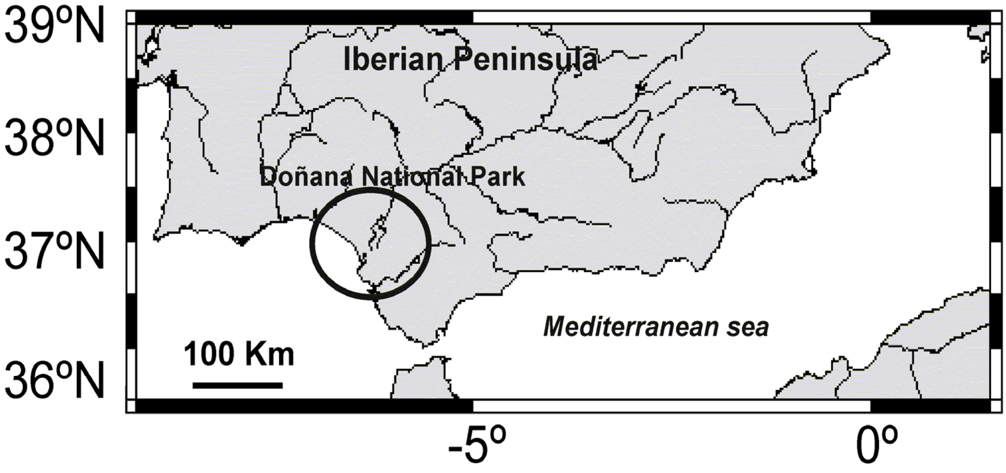

Figure 1: Map of situation. Black circle represents study area (Doñana National Park).

Sample preparation

For this study we selected two stem discs of *Pinus pinea* (DO-33 and DO-36) from Doñana National Park. These samples were previously dried for 48 hours to ambient temperature, polished and cross dated along with ten samples from the same site. To eliminate any influence of the "juvenile effect" observed in young trees (Freyer 1979, Francey & Farquhar 1982), we didn't consider the two first decades to isotopic analysis, so the periods for which data are available are 1925-2007 (for DO-36 individual) and 1945-2007 (for DO-33 individual). An aliquot of 50 mg of wood of each ring was extracted for to carry out cellulose extraction following the method described by Brendel et al. (2000). According to this technique ground sample was treated in acetic acid (80%; v/v) and 0.2 ml of concentrated nitric acid (69%; v/v) for 20 minutes at 120ºC.

Afterwards the samples were washed repeatedly with ethanol, deionised water and acetone. Finally, all samples were freeze dried to remove any contamination.

Carbon isotopic analysis

The isotopic analyses for this study were conducted in the Stable Isotope Laboratory at the Zaidín Experimental Institute (Granada). For carrying out $\delta^{13}C$ analysis an aliquot of 0.5-0.6 mg of cellulose extracted sample was weighed into a tin capsule. The isotopic ratio of $^{13}C/^{12}C$ was determined using a Carlo Erba Elemental Analyzer (NC 1500). The CO_2 produced after combustion was analyzed using a Finnigan Delta^{PLUS} XL isotope ratio mass spectrometer. The δ values are defined as:

$$\delta^{13}C \text{ or } \delta D = [(R_{sample} / R_{standard}) - 1] \times 1000 \text{ (in ‰)}$$

where $R = {}^{13}C/^{12}C$ or D/H ratios.

Stable carbon isotope values are reported relative to the international standard Vienna-Pee Dee Belemnite (V-PDB). Multiple aliquots of in-house standards were analyzed periodically as a check on the analytical precision throughout a run (n=10), which was about ±0.1‰. To eliminate the effects of the general atmospheric decline observed in carbon isotopes of tree rings due to land-use change and the effects of burning fossil fuel, we calculated carbon isotopic discrimination ($\Delta^{13}C$) from equation (1) (Farqhuar et al. 1982)

$$(1) \quad \Delta^{13}C = (\delta^{13}C_{atm} - \delta^{13}C_{wood}) / (1 + \delta^{13}C_{atm}/1000)$$

where $\delta^{13}C_{atm}$ and $\delta^{13}C_{wood}$ are the $^{13}C/^{12}C$ ratios in atmospheric CO_2 and whole wood of each tree ring, respectively, expressed in parts per thousand (‰) relative to the standard Vienna Pee Dee belemnite. For $\delta^{13}C_{atm}$ we used published data from McCarroll & Loader (2004), to 2003 and Leuenberger, (2007) from 2004 to 2007.

Hydrogen isotopic analysis

For hydrogen isotopic analysis, the samples require equilibration or nitration (Ramesh et al. 1988, Schimmelman 1991, Feng et al. 1993) prior to mass spectrometry to remove exchangeable hydroxyl bound hydrogen that constitutes *ca.* 30% of the hydrogen within the α-cellulose monomer. For this study α-cellulose was equilibrated by a method described by Sauer et al. (2009). For hydrogen isotope analysis 0.8 mg of cellulose was weighed into silver perforated capsules. Then, cellulose samples were equilibrated during 8 hours at 115ºC with D-enriched and D-depleted water vapours.

After equilibration, the steam was subsequently replaced by a flow of dry N_2 gas at least 4h at 115ºC to dry the samples. The N_2 supply was dried right away prior to entering the equilibration enclosure by passing the gas through a coil of copper tubing immersed in liquid nitrogen. Finally, the oven was turned off and the equilibration enclosure cooled to room temperature. The equilibrated samples were loaded into the carousel and pyrolised at 1450 ºC using a high temperature elemental analyser (TC/EA) connected to a ThermoFinnigan Delta Plus XL isotope ratio mass spectrometer which was operated in continuous-flow mode. Values of δD were calculated by comparison of sample gases with peaks of H_2 reference gas, and were anchored to the VSMOW scale by comparison with in-house and international standards. Analytical precision throughout a run (n=12) was about ±1‰.

Meteorological data and statistical analysis

Before to investigate the relationship between isotopic data and climate, we compared isotopic series from both trees to each other to see how similar they are. When they are highly correlated, this would indicate a strong common forcing by climate, if they are not, then other factors like competition may be more important.

To investigate the relationship between carbon and hydrogen isotopic composition of growth tree rings and climate we considered climate data (annual and monthly rainfall and annual and monthly temperature) from weather stations near to the study area such as: Palacio de Doñana (36º 59´53´´N - 6º26´37´´E and 6 m.a.s.l.) for the period 1978-2007 and for previous years, meteorological data from Tablada-Sevilla (37º24´10´´N - 6º 0.03´18´´E and 13 m.a.s.l.), Sevilla-Iglesia (Custodio et al., 2005), Gibraltar (36º 8´ 15´´N - 5º 20´ 43´´E and 315 m.a.s.l.) and Rota (36º 39´N - 6º 21´E and 88 m.a.s.l.).

Temporal trends in $\Delta^{13}C$, δD, annual and monthly rainfall, mean annual and monthly temperature were tested by simple linear regression. δD and $\Delta^{13}C$ values of growth tree rings were related by linear correlation with annual and monthly climatic variables (rainfall and temperature).

Results and discussion

Variability hydrogen isotopic values in Pinus pinea growth rings.

The δD time series from the individual *Pinus pinea* trees (DO-33 and DO-36) is shown in figure 2a,b. The values range from -68.4‰ to -38.9‰ for the period 1945-2007, for the individual DO-33 and range from -52.2‰ to -25.1‰ for the period 1925-2007, for the individual DO-36 (Tab. 1). The both δD time series were compared to each other in 10-year periods from 1945 to 2005 (ie, the period common to both). We found positive significant relationships only for the periods 1975-1985 ($r=0.62$, $p<0.05$) and 1995-2005 ($r=0.63$, $p<0.05$).This, may indicate a strong common forcing by climate in recent decades in contrast to previous decades where other factors seem more important, like competition or the different rooting depth.

Then, each δD time series from the individual DO-33 and DO-36 was compared with annual and monthly rainfall and with mean annual and monthly temperature from weather stations near study area. We did not find significant correlation between hydrogen isotopic data and temperature. However, we found negative significant relationships between hydrogen isotopic values and mean annual rainfall ($r= -0.25$, $p<0.05$ for DO-33 and $r= -0.27$, $p<0.05$ for DO-36) (Fig. 2a, b) and with monthly rainfall (Table 2a). For both individual trees the summer rainfall (specifically August for DO-36 and June for DO-33) seem to being the most important limiting factor (as inferred of the highest correlation coefficients, Table 2a). However, the rainfall of the major recharge periods is also related to isotopic data. For DO-36 significant correlations were also found with autumn and winter rainfall (November, December, January and February) (Table 2a). On the other hand, significant correlations for DO-33 were also found with spring rainfall (March and April).

In general, the maximum hydrogen isotopic values coincide with the driest years and *vice-versa* (Fig.2). The reason could be that in dry periods the evaporation from water source and soil is very important and this causes a strong enrichment in heavy isotopes (D). On the one hand, the evapotranspiration from plants cause enrichment in heavy isotopes (D) in water located in the inside of the leaves (Lawrence & White 1984, Krishnamurthy & Epstein 1985). This can be observed, for instance, during the droughts in 1954, 1981, 1992-1995, 2005 (Fig.2). On the other hand is interesting to emphasize that during very rainy years as the beginnings of the 1960s the isotopic values are more negative. This is reflected in δD values from each individual tree (-55.6‰ ±4.4 and -41.8‰ ± 3.3 for DO-33 and DO-36, respectively, averages during the wet period 1960-1963). It is also remarkable that after a strong drought like last one (1992-1995) followed by a very rainy year as 1996 (1181mm) the tree responds with a high isotopic fractionation (δD: -57.6‰ for DO-33 and -49.0 for DO-36) (see Fig. 2). These so negative values could be due to “account effect” which means that more precipitation is corresponded with more negative isotopic values for water (Rozanski et al. 1993).

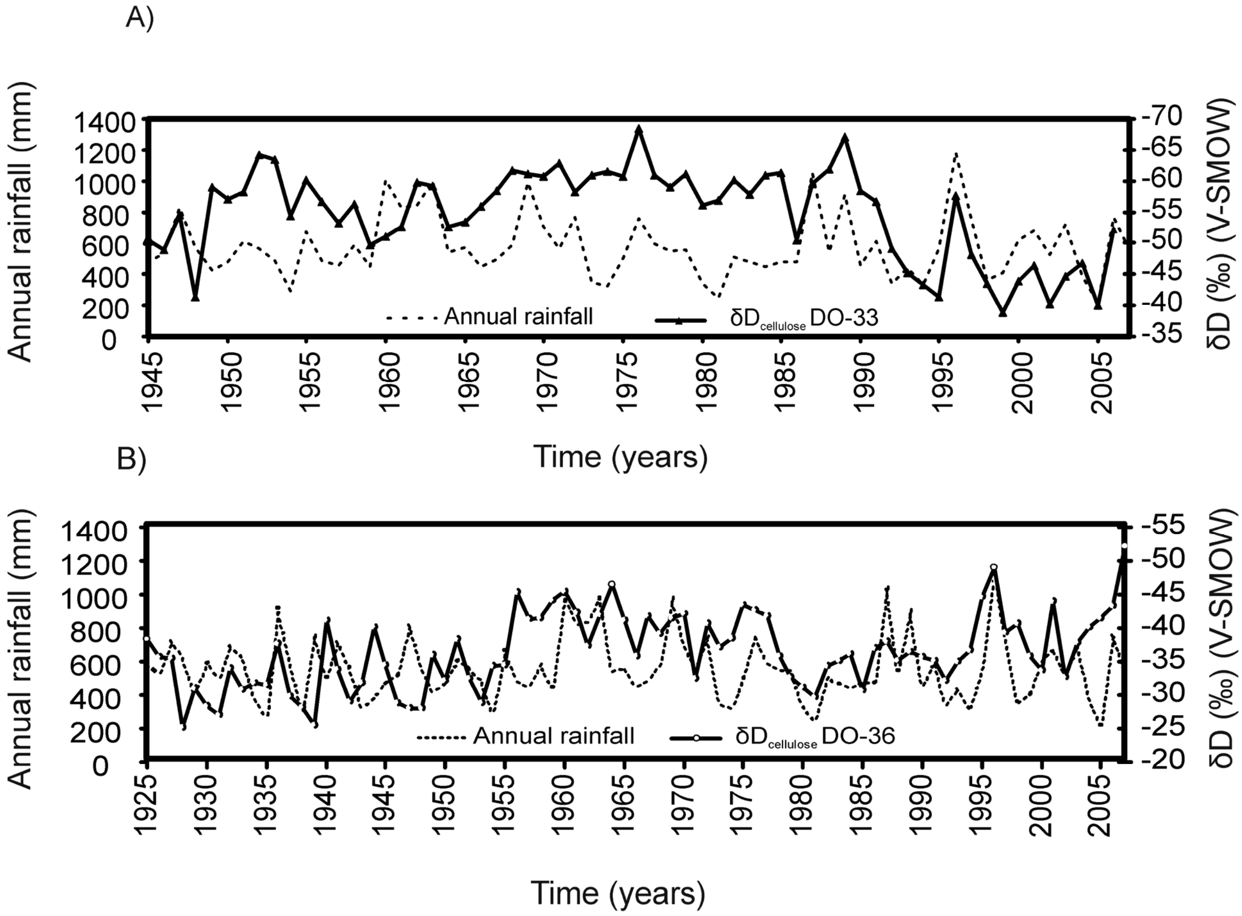

Figure 2: Hydrogen isotopic composition of cellulose from Pinus pinea individual trees: DO-33 (A) and DO-36 (B) in contrast to annual rainfall (doted line). The deuterium scale was inverted.

Variability of carbon isotopic values in Pinus pinea growth rings.

The carbon isotopes ratios of tree rings in this study were expressed in terms of discrimination against ^{13}C to avoid the observed negative trend of δ ^{13}C in atmospheric CO_2 for the 20th century due to increased CO_2 emissions from burning fossils fuels. This atmospheric trend is apparent in most δ^{13}C tree ring series (e.g. Freyer & Belacy 1983, Epstein & Krishnamurthy 1990, Leavitt & Lara 1994, Feng & Epstein 1995a, b, February & Stock 1999, Treydte et al. 2001). Consequently, we used equation 1 (Farquhar et al. 1982) to express carbon isotopes values.

The Δ^{13}C values range from 16.2‰ to 20.5‰ for DO-33 and from 14.4‰ to 19.8‰ for DO-36 (see Fig.3a and Tab.1) for the periods 1945-2007 and 1925-2007, respectively.

High correlation between both carbon isotopic series were found ($r=0.75$, $p<0.001$). This may indicate that the factors that regulate the stomatal conductance are the same for the two trees.

From 1950 to 2007, a negative linear tendency in Δ^{13}C tree ring values was observed (Fig. 3a). This change was about 0.03‰ per year (as suggested from the slope of the regression line, (Fig. 3a).This trend concords with the increase of the mean annual temperature during the last century (Fig. 3b). In fact, we found a negative significant relationship between Δ^{13}C values and average annual temperature ($r= -0.36$, $p<0.05$ for DO-33 and $r= -0.55$, $p<0.05$ for DO-36). There is a period of about 20 years (from 1925 to ~1945) where Δ^{13}C values are higher (using data from DO-36, which have an average of 18.0‰ ±0.7) indicating more favorable weather conditions during this period. In fact the climatic data from meteorological stations considered in this study indicates lower mean annual temperatures during that period (~17.3ºC) (Fig.3). From 1950, we observed a trend towards a decrease in Δ^{13}C values of tree rings with a minimum in the period 1988-1991, which is also the period with the highest annual temperatures (~18.7ºC).

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Monthly linear correlations were also investigated between $\Delta^{13}C$ values and monthly temperature and monthly rainfall (Table 2b). Summer temperature (in particular July temperature) seem to being the most important factor that regulate the stomatal conductance for the two trees (as inferred of the highest correlation coefficients, r= -0.36, $p<0.001$ for DO-36 and r= -0.20, $p<0.1$ for DO-33). In regards to monthly rainfall, spring and summer rainfall are the most influential on the carbon isotopic composition of these tree rings (specifically March rainfall for DO-36 and March, July and August rainfall for DO-33).

These results suggest that in years when temperatures are higher (particularly, summer temperature) and rainfall are scarce (specifically spring and summer rainfall), plant stomata close to minimize water loss (stress defence mechanism). Consequently, the concentration of CO_2 inside the leaves decreases and therefore discrimination against CO_2 molecules with the heavy isotope ($^{13}CO_2$) is smaller (Francey & Farqhuar 1982, Ehleringer et al. 1993, Saurer et al. 1995).

Table 1: Isotopic variability between individual trees. Maximum, minimum and average hydrogen data and carbon isotopic discrimination values.

Tree	δD(‰) (V-SMOW)$_{max}$	δD(‰) (V-SMOW)$_{min}$	δD(‰) (V-SMOW)$_{aver}$	Δ^{13}C(‰) (V-PDB)$_{max}$	Δ^{13}C(‰) (V-PDB)$_{min}$	Δ^{13}C(‰) (V-PDB)$_{aver}$
DO-33	-38.9	-68.4	-54.5±7.3	20.5	16.2	18.3±0.9
DO-36	-25.1	-52.2	-36.5±5.4	19.8	14.4	16.9±1.1

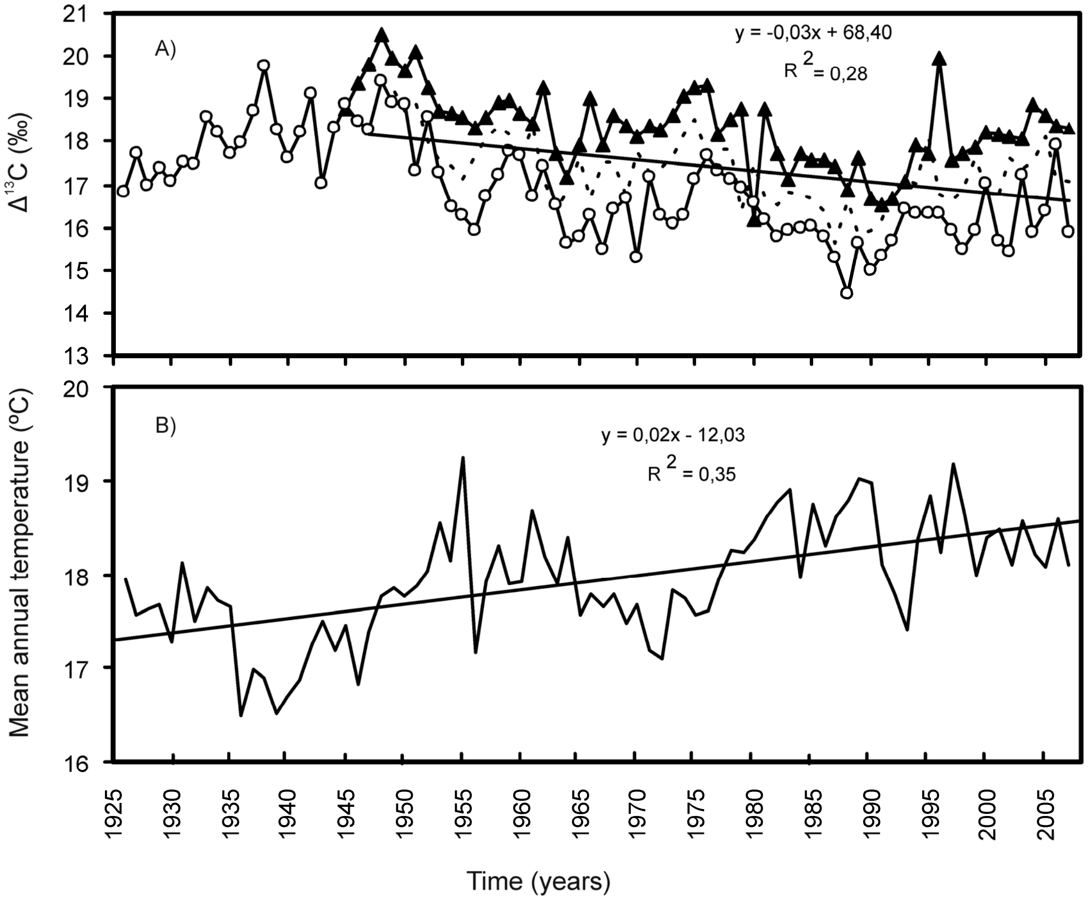

Figure 3: A) Carbon isotopic discrimination of cellulose from DO-33 individual (black triangles) and DO-36 individual (white circles). Regression line from the average values of the two individuals (straight black line). B) Mean annual temperature of the study area and regression line (straight black line).

Table 2: A) Correlation coefficient (r) and significance (p) between hydrogen isotopic data of the two trees (DO-36 and DO-33) with monthly rainfall. B) Correlation coefficient (r) and significance (p) between carbon isotopic data of the two trees (DO-36 and DO-33) with monthly rainfall and monthly temperature. In bold letter, the highest correlation coefficient.

A)

Rainfall	**Months**	**r**	**p**
DO-36	January	-0.20	p<0.1
	February	-0.23	p<0.05
	August	**-0.24**	p<0.05
	November	-0.20	p<0.1
	December	-0.20	p<0.05
DO-33	March	-0.22	p<0.1
	April	-0.25	p<0.05
	June	**-0.26**	p<0.05
	August	-0.22	p<0.1

B)

Temperature	**Months**	**r**	**p**
DO-36	May	-0.22	p<0.05
	June	-0.20	p<0.1
	July	**-0.36**	p<0.001
	August	-0.22	p<0.05
DO-33	July	-0.20	p<0.1
Rainfall	**Months**	**r**	**p**
DO-36	March	0.27	p<0.05
DO-33	March	**0.34**	p<0.01
	July	0.22	p<0.1
	August	0.23	P<0.1

Conclusions

The results obtained in this study suggest that the isotopic composition of tree rings of *Pinus pinea* from Doñana National Park is a useful tool to understand the isotopic variability associated to climate shifts and with global change on Mediterranean regions.

Despite analytic difficulty of hydrogen stable isotopes in tree rings cellulose of *Pinus pinea,* significant correlation exist between climate data of Doñana National Park and isotope data. The driest years agree with the less negatives isotopic values, due to ground and surface water evolution evaporation effects which are reflected in more positives values of δD of tree rings cellulose. On the other hand, the very rainy years corresponded to more negatives isotopic values.

The most important monthly rainfall in the isotopic composition of hydrogen is summer rainfall for the two trees, however the rainfall of the major recharge periods (like winter and spring) is also reflected in the hydrogen isotopic composition of cellulose.

At the study area an increase in mean annual temperature during the last century was observed which seem to be causing stress on the tree mass as is manifested by a decrease in carbon isotopic discrimination. In fact, we found significant relationships between mean annual temperature, summer temperature (May, June, July and August) with $\Delta^{13}C$ data. The spring rainfall (March rainfall) and summer rainfall (July and August rainfall) was also significantly correlated with $\Delta^{13}C$ data. This means that temperature (specifically summer temperature) and seasonal rainfall (particularly summer and spring rainfall) are the main factors that controls stomatal conductance on *Pinus pinea* from Doñana National Park.

Acknowledgments

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Toward multi-parameter records (ring width, δ^{13}C, δ^{18}O) from tropical tree-rings - A case study on *Tectona grandis* from Java, Indonesia

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Introduction

Climate in Indonesia is mainly dominated by the equatorial monsoon system and tends to be linked to ENSO warm events which result in extensive droughts over the Indonesian archipelago (Hackert and Hastenrath 1986). Hence, dendroclimatological studies from this region carry a great potential to improve land-based rainfall proxy records. The potential of tropical tree species as recorders of climate variability has not been fully exploited due to the frequent lack of visible, annual growth rings. However, as one of a few tropical tree species Teak (*Tectona grandis*) shows distinct annual growths boundaries. In earlier studies ring-width chronologies from Indonesian teak have been established and used for climatic reconstructions (e.g., Berlage 1931; D´Arrigo et al. 1994; D´Arrigo et al. 2006). Multi-parameter studies, comprising wood anatomy or tree-ring stable isotopes, are still scarce in the tropics and the influence of climate and other environmental factors on tree-ring stable isotope ratios of Indonesian teak has not been studied in detail, yet. Here we present the first stable isotope (δ^{13}C and δ^{18}O) records back to AD 1900 developed from Indonesian teak. These parameters as well as tree-ring width chronologies from the same material were compared with climate data in order to test their potential for climate reconstructions.

Materials and Methods

Study site and climate conditions

The samples were collected in a lowland rain forest at an elevation of around 380 m a.s.l.. The study site, named Donoloyo, is located 90 km east of the city of Yogyakarta in the eastern part of Central Java, Indonesia (07°52'S, 111°11'E), as shown in figure 1.

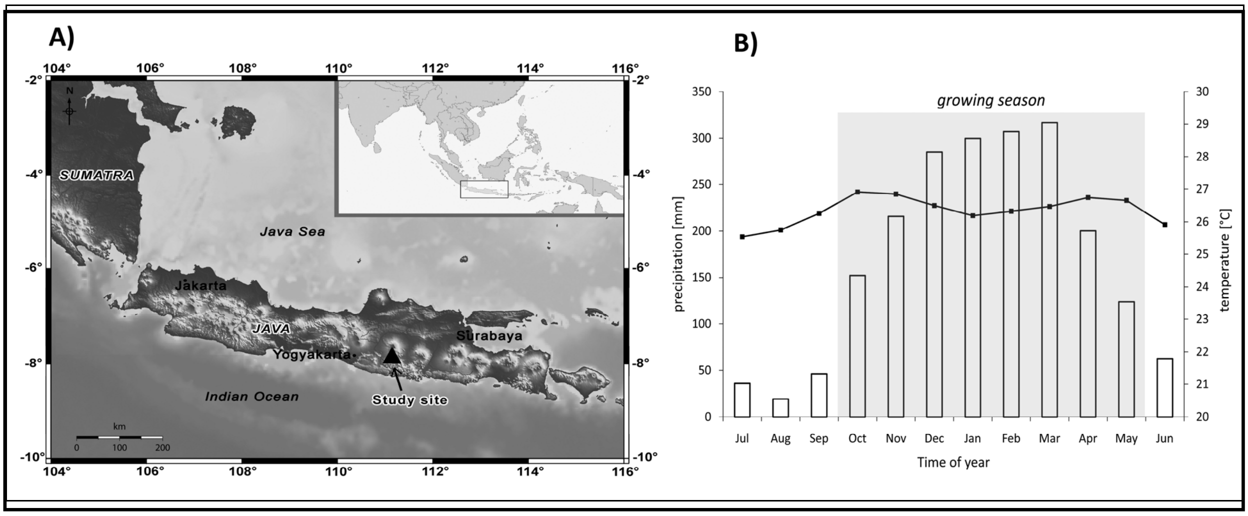

Figure 1: A) Map showing the location of the study site (Donoloyo) in a lowland rain forest (380 m a.s.l.) in the eastern part of Central Java (07°52'S, 111°11'E). B) Mean monthly precipitation (bars) and temperature (line) at the study site derived from gridded climate data (CRU TS 3.0, 1901-2006). The growing season is highlighted in grey.

The study site, among several others, was part of earlier investigations on ring width by D`Arrigo and co-workers. It revealed significant but comparatively low correlation between SST and growth (e.g., D'Arrigo et al. 2006). We re-sampled the site in November 2008 and initiated a stable isotope study in order to test whether or not the additional parameters provide better or different relationships to climate data than ring width have revealed in previous studies (Berlage 1931; Jacoby & D'Arrigo 1990; D'Arrigo et al. 2006; D'Arrigo et al. 2008).

In this study, gridded (0.5°x0.5°) climate data, provided by the Climatic Research Unit of East Anglia University, Norwich, UK covering the time period 1901-2005 (CRU TS 3.0, Mitchell and Jones 2005), were used for correlation analyses. The long-term mean annual values for precipitation and temperature are 2062 mm and 26.3°C, respectively. Precipitation is assumed to be the limiting factor for tree growth in the study area, because of a distinct seasonality, as well as well drained soil. Central and Eastern Java are influenced by the equatorial monsoon climate which is characterized by a rainy season (north-west monsoon), persisting from November to April and a dry season (south-east monsoon) from May to October (Fig. 1B). The vegetation period (growing season) for *Tectona grandis* in Central and Eastern Java generally lasts approximately from the beginning of October to the end of May. Leaf flushing starts with the onset of the monsoon rains and flowering occurs toward the end of the rainy season. Approximately from June/July to September, that is, during the dry season, the species is leafless and consequentially in a state of cambial dormancy (Coster 1927; Coster 1928).

Sample material

For this study two cores each from 16 dominant *Tectona grandis* trees were collected. Ring widths were measured subsequently and cross-dated using the programs TSAPWin (Rinn 2005) and COFECHA (Holmes 1983). The final tree-ring width chronology (TRW) is based on cores from 11 trees, 5 individuals were not included due to cross-dating problems. For dating purposes, we followed Schulman's (1956) convention for the southern hemisphere, which assigns to each tree-ring the starting date of radial growth. All trees of our site chronology were, in average, older than 240 years, however, only the 19th and 20th centuries were investigated in this calibration study. This was done for allowing a direct comparison of raw values of ring-width and stable isotope records over a period in which any age-related growth trends can be neglected as being minor of higher order.

For the isotope analyses, five cores of different trees were chosen according to the following criteria: i) correct dating and high synchronicity of ring-width sequences as indicated by statistical parameters such as Gleichläufigkeit (GLK), Cross-Dating-Index and t-value, ii) good wood quality and iii) as few as possible problematic zones (such as false or narrow rings). For the period of AD 1900-2007 the entire annual rings from all cores were separated with a scalpel and finely ground to assure homogeneity. Resin extracted wood material was used instead of cellulose due to some very narrow rings which would have not provided sufficient amounts of cellulose for the conventional online IRMS determination of $\delta^{13}C$ and $\delta^{18}O$. However, recent research has shown that the cellulose extraction is not as crucial as had been suggested previously (Borella et al. 1998; McCarroll & Loader 2004; Verheyden et al. 2005; Taylor et al. 2008). Consequently, only extractives, such as wood resins and oils, but also glue, pencil and chalk remains were removed from the wood with boiling de-ionized water and ethanol in a new multiple sample isolation system for solids (Wieloch et al. 2010). The $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios were measured by combustion and low-temperature pyrolysis (at 1080°C), respectively, using an elemental analyzer (Model NA 1500; Carlo Erba, Milan, Italy) coupled to an IRMS (Isotope Ratio Mass Spectrometer; Micromass, Ltd. Manchester, UK). The results are given in the conventional δ notation relative to the international standards VPDB and VSMOW. Sample replication resulted in a precision of better than ±0.1‰ for $\delta^{13}C$ values and ±0.25‰ for $\delta^{18}O$ values. Carbon isotope records are displayed as discrimination Δ, which is the shift between the carbon isotope ratios of the air relative to the isotope ratios of the tree-rings. Similarly, to the conventional δ notation in ‰, the discrimination Δ in ‰ follows as: Δ [‰] = ($\delta^{13}C_{atm}$ – $\delta^{13}C_{TR}$)/(1 + $\delta^{13}C_{TR}$ x 10^{-3}). Hence, the records of Δ are free from the well-known trend of declining $\delta^{13}C_{atm}$-values due to fossil fuel burning and deforestation since AD 1850 (e.g. Helle & Schleser 2004).

The resulting series were compared with the CRU 3.0 (precipitation, air temperature) and HadSST2 gridded data sets (sea surface temperature, SST) (Rayner et al. 2006). Data from meteorological stations were acquired, but not used in this study due to short lengths and a lot of missing values.

In order to investigate the climate-proxy relationships, precipitation, air temperature and SST covering the periods 1901-2005 and 1901-2007, respectively, were compared with tree-ring data (TRW, Δ, $\delta^{18}O$) by calculating Pearson's correlation coefficient.

Results

Site chronologies

The three chronologies of tree-ring width (TRW), ^{13}C discrimination (Δ) and oxygen isotope ratio ($\delta^{18}O$) are shown in figure 2.

The top graph of figure 2 shows the dated ring width series along with the mean chronology. The series from 11 trees agree reasonably well (mean inter-series correlation of 0.54, GLK=69%, cf. Table 1), and the EPS of 83% (slightly below the commonly adopted value of 85%) indicates that the chronology is replicated sufficiently back to AD 1800. However, the variability of the raw dataset is not stable over time with obvious periods of high scatter (1860-1880/1900-1920/1940-1970). Furthermore, a trend toward greater variability is visible over the second half of the 20th century. Although human influence cannot be excluded, a strong direct impact is very unlikely since the site is a protected area, used for seed collection since many years.

In the middle plot of figure 2, the carbon isotope chronology, presented as ^{13}C discrimination (Δ), derived from five individuals and selected according to the criteria described above, is displayed. The mean inter-series correlation is rather low (r=0.41) as well as the EPS value (EPS=0.64) (cf. Tab. 1). Even without the outlier tree r and EPS increase only slightly to r=0.44 and EPS=0.67. For comparison, the EPS value for ring width of those five trees is of the same order, namely 0.68. The mean year-to-year variability of Δ is rather low (< 1‰, with few exceptions) as compared to the differences among the trees in mean Δ (2-4‰) and to tree-ring $\delta^{18}O$. This indicates that ecological long-term changes seem to have a much stronger impact on Δ than short-term variations. Apart from this, one tree shows much higher ^{13}C discrimination than the others (see dashed line in Fig. 2). According to the model concept of carbon isotope fractionation during photosynthesis of C3-plants (Farquhar et al. 1982) high ^{13}C discrimination stands for a high ratio of c_i over c_a (c_i = leaf internal CO_2 concentration; c_a = atmospheric CO_2 concentration) due to a high stomatal conductance and/or a low assimilation rate. Interestingly, the tree with the higher ^{13}C discrimination is characterized by rather slow growth in general. A fact, that points to a strong impact of the assimilation rates on Δ. The averages of Δ of all the trees are relatively close for the first half of the 20th century. However, since the end of the 1950s two trees display a distinct increase in Δ, whereas two other trees show no changes and one a slight decline in Δ. This suggests that the individual tree responses are changing in time, probably due to differences in genetics or micro site conditions (e.g., nutrient supply).

The results for oxygen isotopes ($\delta^{18}O$) from the same five individuals are shown in the bottom plot of figure 2. In contrast to ^{13}C discrimination, the individual series are quite well correlated (r=0.53, GLK=74%, EPS=0.85, cf. Table 1) and the variability is rather stable throughout the entire 20th century.

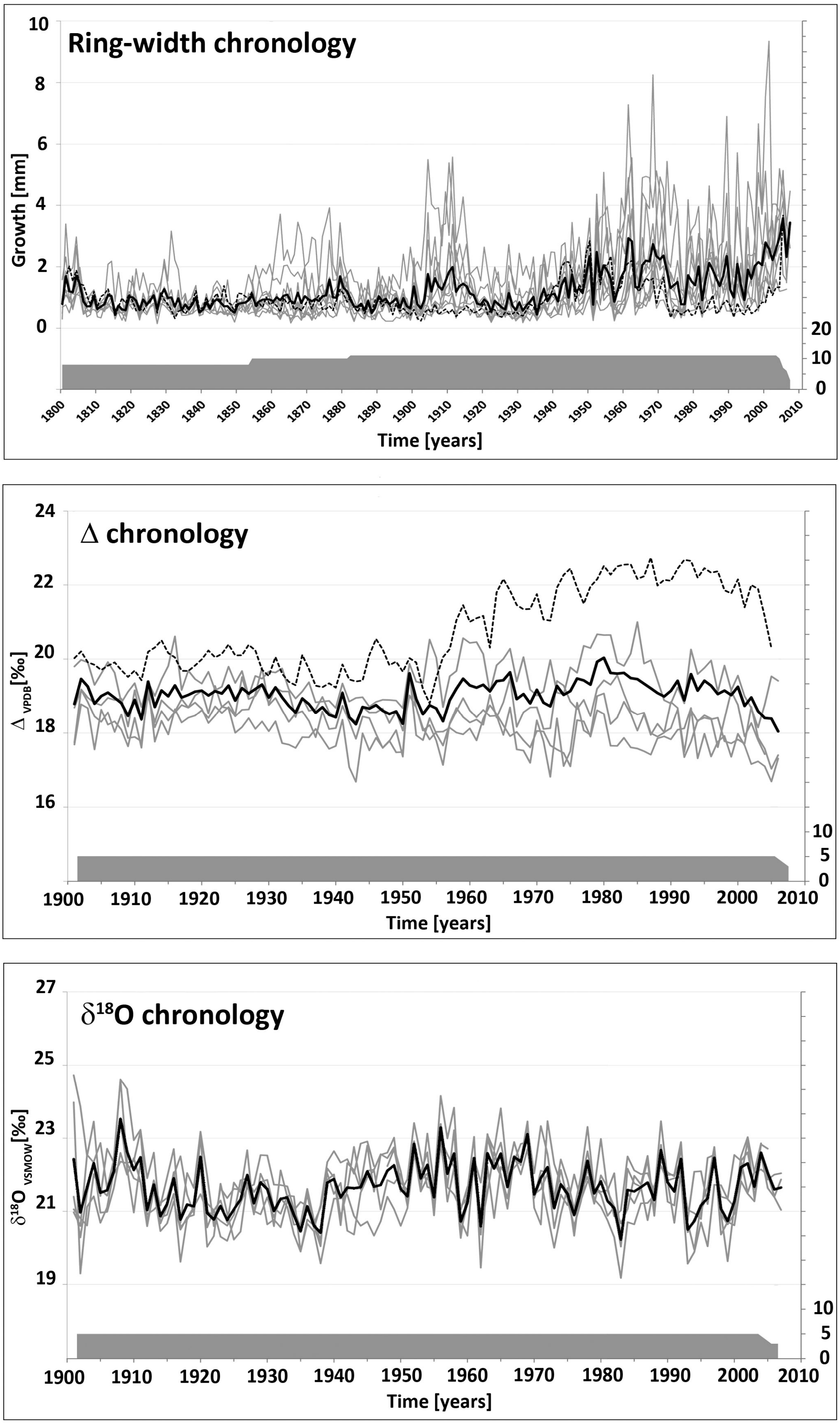

Figure 2: Raw tree-ring width and isotope chronologies and sample depth (thick black lines represent the mean chronology of each parameter). Note that the tree with rather high ^{13}C discrimination (Δ) is characterized by slow growth (dashed graphs in top and mid panel).

Table 1: Descriptive statistics for the tree-ring width (TRW), ^{13}C discrimination (Δ) and oxygen isotope (δ^{18}O) chronologies. CL: length of chronology; SD: standard deviation; GLK: Gleichläufigkeit; NET: see Esper et al. (2001); Cor: Series intercorrelation; AC 1: first order serial autocorrelation

	Time-span	CL	# of trees	mean	SD	GLK [%]	NET	corr	EPS	AC 1
TRW	1800-2007	208	11	1.69	1.22	69	0.64	0.54	0.83	0.64
Δ	1900-2007	108	5	19.02	0.37	64	0.41	0.41	0.64	0.54
δ^{18}O	1900-2007	108	5	21.65	0.66	74	0.28	0.53	0.85	0.22

Climate response

The climate response plots present Pearson's correlations between the stable isotope records and the climate data, respectively (Fig. 3). Correlations between TRW and climate are not shown here because they do not differ from previous analyses (D´Arrigo et al. 1994, 2006, 2008).

We grouped and arranged the data according to the growing period of the trees, that is, October of the current year (date of the tree ring) to September of the following year.

The Δ chronology (Fig. 3, 2nd row) shows no highly significant correlation with any climate parameter. However, the response to monthly and seasonal mean temperatures is mainly positive in sign, whereas precipitation of previous year`s October and November has a negative influence on ^{13}C discrimination.

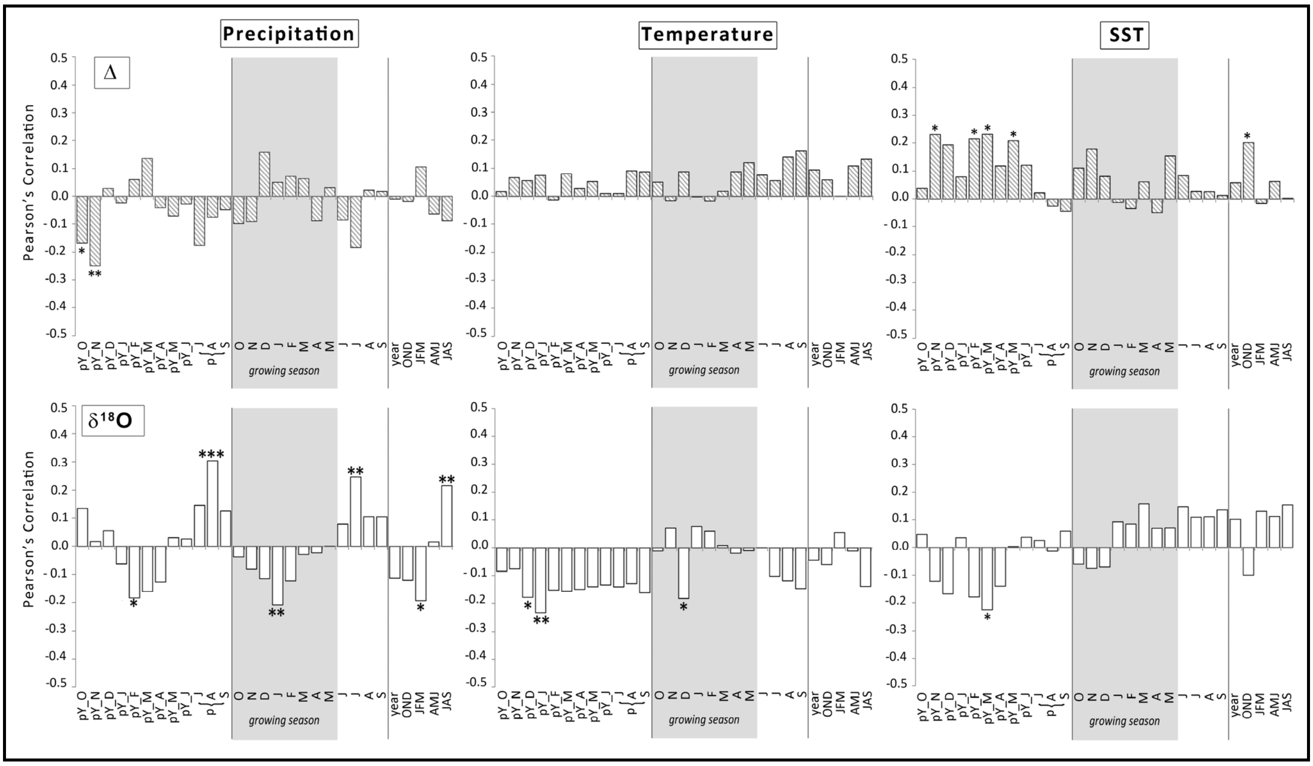

*Figure 3: Correlations between Δ- and δ^{18}O- records and climate data for the period 1901-2005. The diagrams for each climate parameter are separated into three parts by vertical lines. The left part displays the months (previous year October to current year September) prior to the actual growing period (grey shaded area), the middle parts shows the months of the actual growing period (October to September) and the right part depict seasonal means. Stars denote the significance levels: * 90% / ** 95% / *** 99%.*

A climate response analysis of δ^{18}O (Fig. 3, 3rd row), generally shows significant positive correlations with precipitation of the dry season and negative relationships with the wet season. Pre-season August, the driest month of the year directly before growth begins, displays the highest significance (r=0.30, for p<0.01). As for the growing period, precipitation in January has the strongest negative effect on tree-ring δ^{18}O at our site. The relationships between δ^{18}O and temperature as well as SST show notable significance in some periods. The air temperature has some weak negative relationship with tree-ring δ^{18}O, whereas SST shows no clear pattern of tree response.

Discussion and Conclusions

We developed a 208-year long tree-ring width chronology (AD 1800-2007) and 108-year long carbon and oxygen isotope chronologies (AD 1900-2007) of *Tectona grandis* from a site of eastern Central Java.

Climate correlation tests show that tree growth is influenced by seasonal precipitation amounts and that it has a strong positive response to SST data which is a moisture indicator, similar to the results of previous studies from D´Arrigo et al. (1990, 1994, 2006).

The correlations between the carbon isotope record (Δ) and any of the three climate parameters were not highly significant. This may be due to the poor representativeness (low EPS and GLK) of the selected five sample trees. It may also be due to a very minor influence of climatic quantities on the processes underlying carbon isotope variability, i.e., ^{13}C discrimination and carbon assimilation. More samples need to be analyzed and other environmental factors than climatic factors need to be studied to understand the carbon isotope variability at the Indonesian site.

Drought influenced sites very often showed good correlation between tree-ring δ^{13}C and precipitation in semi-arid or arid regions. However, during the vegetation period humid conditions persist at our site, and some kind of drought stress at the beginning or the end of the growing period may not have a significant impact.

Indeed, the δ^{18}O record shows notable significant correlation coefficients with precipitation of pre-season August (driest month) and current year January (wettest month). Interestingly, the correlations found are opposite in sign. Pre-season August has a positive relationship with tree-ring δ^{18}O, while the correlation with January is negative. This is very likely because the rainfall of pre-season August reflects the highest δ^{18}O while precipitation in January is characterized by the lowest δ^{18}O signature of the year (Fig. 4). Hence, tree-ring δ^{18}O probably reflects the relative portion of August to January precipitation with subsequently changing isotope signatures derived from the so-called "amount effect" and/or changing origin of air moisture (e.g., Araguas-Araguas et al. 2000).

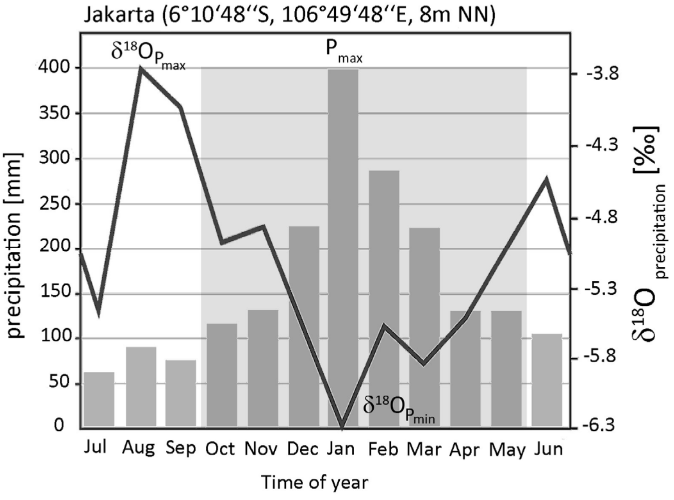

Figure 4: Average monthly precipitation sums (grey) and $\delta^{18}O_{Precip}$ in precipitation (black) for Jakarta/Indonesia. The grey shadow marks the growing season. (GNIP: http://www-naweb.iaea.org)

An influence of evapotranspiration on ^{18}O-enrichment of leaf water could not be detected, probably because the effects on tree-ring δ^{18}O act in the same direction as changes in δ^{18}O of precipitation under dry and wet conditions. Dry conditions result in high ^{18}O-enrichment in precipitation as well as in leaf water and wet conditions evoke the same effects in opposite direction. An influence of ground-water due to water uptake from deeper soil during the vegetation period seems to be unlikely since the soil at the site is well-drained and teak has a shallow root system.
In conclusion, the results of this calibration study point out that the isotope ratios of carbon and oxygen show weaker climate signals than tree-ring width, at least when only 5 trees are considered and the chronologies show relatively weak values of EPS and GLK etc. and thus more trees need to be analyzed. Furthermore, future efforts will focus on highly resolved intra-annual δ^{18}O studies which may provide more detailed insights into the influence of seasonally changing precipitation amounts and $\delta^{18}O_{Precip}$ on tree growth and tree-ring δ^{18}O records. This may improve land-based rainfall reconstructions based in multiple tree-ring parameters.

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Climate impact on growth dynamics and intra-annual density fluctuations in Aleppo pine (*Pinus halepensis*) trees of different crown classes

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Introduction

Tree radial-growth models are valuable for simulating the impacts of climate change on future growth of forest species. Understanding how forest growth responds to climate is a key element for a deeper knowledge of forest dynamics in a changing environment. Trees growing in extreme conditions respond strongly to climate variations (Fritts 1976). Mediterranean regions, as transitional climate zones between arid and humid regions of the world, are areas where climatic changes may have the greatest effects (Lavorel et al. 1998).

Different Mediterranean pine species have been analyzed to detect relationships between climatic trends and tree growth. *Pinus pinea* is positively correlated with precipitation in southern Portugal (Campelo et al. 2007). This fact has also been reported for *Pinus pinaster* in central Portugal (Vieira et al. 2009) and in central Spain (Bogino and Bravo 2008), for *Pinus nigra* in southeastern Spain (Martin-Benito et al. 2008) and for *Pinus sylvestris* towards its southern and western distribution limit (Bogino et al. 2009). Growth rate of *Pinus hapepensis* is sensitive mainly to temperature variations during the wet season and to soil humidity variations during the dry season in southern Italy (Attolini et al. 1990). In France, Rathgeber et al. (2005) concluded that *Pinus halepensis* growth is controlled by soil water availability during the growing season. In Greece, the growth of Aleppo pine is positively related with the winter and spring precipitations and negatively with the temperatures of the spring months (Papadopoulos et al. 2008).

Wood anatomical features in tree rings have been interpreted as indicators of environmental change (see for instance Briffa et al. 2003). Species growing under Mediterranean climate, with summer droughts and high inter-annual variability in precipitation and temperature, commonly show distinct anatomical characteristics in tree rings (Schweingruber 1993). Intra-annual density fluctuations (IADFs) are characterized by latewoodlike cells within the earlywood and earlywoodlike cells within the latewood (Fritts 2001). Consideration of IADFs in dendrochronological studies allows detailed analysis of climatic events within the growing season. Different studies of pine species showed a good correlation between IADF formation and climate in the Mediterranean area. IADFs were mainly correlated with precipitation in autumn in *P. pinaster* in Portugal (Vieira et al. 2009) and with precipitation in late winter and spring and higher temperatures in central Spain (Bogino & Bravo 2009). IADFs were caused by precipitation events early in summer following a water deficit early in the growing season in *Pinus pinea* in southern Portugal (Campelo et al. 2006). However, information about the impact of climate on IADFs of *Pinus halepensis* is scarce.

Aleppo Pine (*Pinus halepensis* Mill.) is a native pine of the Mediterranean region, where it is one of the main species in the present landscape. Therefore, the study of the impact of climatic variables (temperature and precipitation) on its radial growth is of major interest. The objectives of the present study were to identify relationships between radial growth and climate for different crown classes of Aleppo pine (*P. halepensis* Mill.), to quantify the presence of intra-annual density fluctuations (IADFs) according to crown class and cambial age and to establish the relationships between IADFs and climate.

Material and Methods

Eight sampling sites were selected throughout the natural distribution area of *Pinus halepensis* in the Iberian Peninsula (Fig. 1), and fifteen trees from each crown class (dominant and suppressed) were selected within each sampling site. Dominant trees were defined as those standing above all other trees in its vicinity and receiving full light from above, whereas suppressed trees were defined as those growing below the tree canopy.

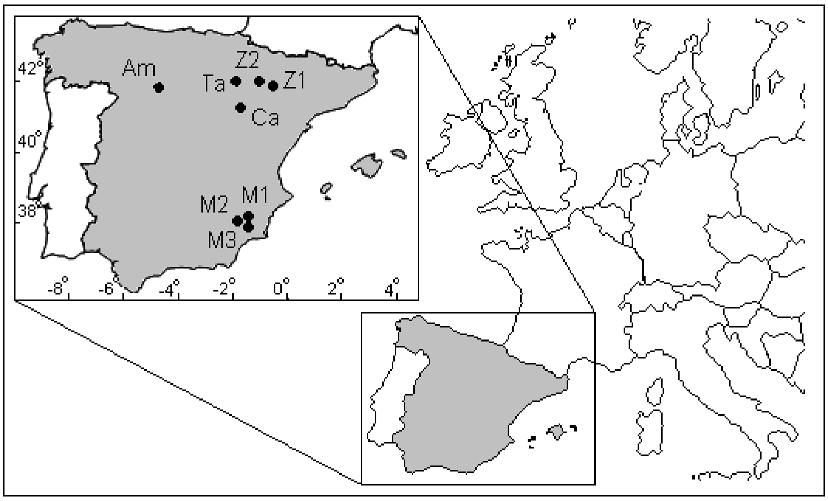

Figure 1: Study areas of Pinus halepensis in the Iberian Penninsula.

In sites Za1 and Za2 only dominant trees were sampled. Therefore, a total of fourteen tree-ring chronologies (eight dominant and six suppressed) were analyzed. From each tree two cores were extracted at 1.30 m above ground. The increment cores were air dried and mounted on wooden supports and dated according to standard dendrochronological techniques (Stokes & Smiley 1968). The preparation of the samples was done using a diamond flycutter (Kugler F500).

The program COFECHA (Holmes 2001; Grissino-Mayer 2001) was applied to assess dating accuracy. According to standard methods in dendrochronology trees exhibiting correlation values with the master chronology below 0.4 were excluded (Vieira et al. 2009).

To eliminate biological trends in tree-ring series and to minimize growth variations that are not common by most trees, the program ARSTAN (Cook and Holmes 1984; Holmes 2001) was used. Standardization removes geometrical and ecological trends while preserving inter-annual high-frequency variations that are presumably related to climate. To obtain a master chronology for each study site and crown class, the standardized series were averaged.

Chronology quality was evaluated using the signal-to-noise ratio (SNR), the proportion of the variability explained by climate or other casual factors divided by the residual or unexplained variability (Fritts & Swetnam 1989); and the expressed population signal (EPS), which indicates the degree to which the particular sample chronology portrays a hypothetically perfect chronology (Wigley et al. 1984).

Relationships between climatic data and tree-ring widths

Mean monthly temperature and total monthly precipitation were grouped in climatic seasons (winter, spring, summer and fall) and regressed against ring-width indices in order to assess climate-growth relationships. DENDROCLIM 2002 (Biondi & Waikul 2004) was applied to calculate correlation and response functions utilizing bootstrapped error estimates (Guiot 1991).

Intra-annual density fluctuations

Tree-rings were visually examined for IADFs. An IADF is defined as a layer of cells within a tree ring characterized by different shape, size and wall thickness (Kaennel & Schweingruber 1995). IADFs show a continuous transition in opposite to the annual rings boundary (Fritts 2001). Because of the variability of IADFs tangentially and vertically within the tree ring along the stem the IADFs were only considered when present in both cores, in the same tree ring.
As the number of samples changed over time, the relative frequency was calculated using:

[1] $F = n/N$

where F is the relative frequency of IADF in a particular year; n the number of trees that formed the IADF and N the total number of trees analyzed. Potential biases in the frequency were assessed by calculating the stabilized IADF frequency (f), according to (Osborn et al. 1997):

[2] $f = F^{0.5}$

Data analysis

The logistic equation form was chosen to model the probability of occurrence of IADFs [3]:

[3] $P = (1.0 + e^{(-z)})^{-1}$

where P is the probability of IADFs and $Z = b0+b1(x1)+b2(x2)+\ldots\ldots+bk(xk) + \varepsilon$; where x1; x2..... xk are the climatic variables and b0; b1; b2 ….. bk are unknown parameters of the model and ε is a normal random error N (0,1); and *e* is the exponential operator. The equation can be formulated to accept a binary variable such as occurrence of IADFs, and the parameters can be estimated by maximum-likelihood methods. The resulting prediction is bounded by 0 and 1. Monthly rainfall and mean monthly temperature were used as explanatory variables. The hydrological year was defined as a period of 12 months, from previous year October to current year September. A stepwise selection method was used to find the best model.
The alternative fits were evaluated on the basis of the Akaike criterion (AIC), the –2*Log Likelihood, the area under the receiver operating characteristic (ROC) curve and the expected behavior - as indicated by the signs of the estimated parameters. The ROC curve is displayed for the models and the area underneath was calculated as a value of the accuracy of the model. Values larger than 0.80 indicate an excellent discrimination (Hosmer & Lemeshow 2000). This curve relies on false/true positive/negative tests, and the sensitivity is indicated by the proportion of correctly classified events and the specificity by the proportion of correctly classified non-events (Hair et al. 1998). This model has previously been used to estimate the probability of occurrence of IADFs in *Pinus pinaster* subsp. *mesogenesis* in the Iberian Peninsula (Bogino & Bravo 2009a). The PROC LOGISTIC of SAS 9.1 (SAS Institute Inc. 2004) was used to fit the model. Samples were first grouped according to site location (Palencia, Aragón and Murcia), age (younger than 80 years and older than 80 years) and crown class (dominant and suppressed).

Results

The mean chronology of the suppressed trees showed slightly higher mean sensitivity values (0.30 for dominants and 0.33 for suppressed). However, in Ampudia dominant trees were more sensitive than suppressed trees. SNR values were also higher for dominants than for suppressed (26.64 and 12.77). The mean chronology of the dominant trees also showed higher variance and mean inter-series correlation values than the mean chronology of the suppressed trees (Tab. 1).

Table 1: Descriptive statistics of the dominant and suppressed chronologies. SD: standard deviation; MS: mean sensitivity; SNR: signal to noise ratio; EPS: expressed population signal; Var: variance in first eigenvector; and inter-series correlation (RBar): mean correlation among trees.

Social class	Period	Core number	Ring number	Age range	SD	MS	SNR	EPS	Var.	RBar
Dom.	1915-2008	22	1139	27-95	0.27	0.30	26.64	0.94	0.60	0.70
Suppr.	1917-2008	19	732	20-92	0.32	0.33	12.77	0.95	0.56	0.63

Precipitation appeared to be the main factor influencing tree growth with significant values in all seasons, while temperature reached only weak correlation values in two of the five seasons. Spring precipitation showed the most significant positive correlations followed by summer and winter previous to the growing season.

A total of 13502 tree rings were analyzed from trees from the eight sampling sites and a total of 107 IADFs were found. Samples were grouped according to site location, age and crown class. The percentage of trees with IADFs was rather similar for young and old stands. However, the percentage of IADFs and the stabilized IADF were higher for young stands than for old stands. The percentage of trees with IADFs and the percentage of IADFs were both higher for suppressed than dominant trees. Mean stabilized IADF was the same for both crown classes.

IADF frequency in relation to calendar year showed an increase in IADFs from the 1980s to the present. 1983, 1989, 1995 and 1999 were the years with more IADFs, with a stabilized frequency higher than 0.2. The nonlinear logistic equation form was chosen to model the probability of occurrence of IADFs with monthly precipitation and mean monthly temperature as variables.

The logistic function estimated that 10 monthly climatic variables out of 24 had a significant effect on predicting future IADFs. The model showed that, without considering crown classes, precipitations in October, December, March, April, June and mean monthly temperatures in June and September had a positive impact on the formation of IADFs, while precipitations in November and July and mean monthly temperatures in May had a negative impact on the formation of IADFs. December and April precipitation totals had a positive impact on the formation of IADFs in both dominant and suppressed trees, while precipitations in July had a negative impact. The area underneath the ROC curve was 0.918 for all trees, 0.917 for dominant trees and 0.943 for suppressed trees. The accuracy of the model is also sufficient to use it to predict occurrence of IADFs.

Discussion

Pinus halepensis shows significant correlations between trees growing at the same site, high expressed population signals and accurate statistical values suggesting a clear response to environmental factors. In addition, it confirms the tendency of Mediterranean species to develop diagnostic anatomical structures (Schweingruber 1993). We found common radial growth patterns among dominant and suppressed series in the same site. These results agree with previous studies in the Iberian Peninsula suggesting that pine species growing in the southern dendroecological section contain a common growth response to environmental factors (Richter et al. 1991; Bogino & Bravo 2008).

Descriptive chronology statistics suggest that the tree-ring series reflect one or more associated factors (including climate), and a strong response of radial growth to changes in climatic conditions as indicated by the mean sensitivity values (MS) from 0.21 to 0.40 that are higher than the 0.16 to 0.34 values found in previous studies on pine species (*Pinus sylvestris* L., *Pinus nigra* Arnold, *Pinus pinaster* Ait. and *Pinus mugo* ssp. *uncinata* Turra.) in the Iberian Peninsula (Richter et al.

1991; Bogino & Bravo 2008; Martin-Benito et al. 2008; Bogino & Bravo 2009; Bogino et al. 2009; Vieira et al. 2009).

The expressed population signal (EPS) ranging from 0.89 to 0.98 is in all cases higher than the critical level of 0.85 suggested by Wigley et al. (1984), which implies that the chronologies are representative of regional tree growth. First eigenvector variance indicated good homogeneity within the same site. It can be concluded that the fourteen mean chronologies have high MS, SNR, EPS and percentage of the variance accounted for by the first eigenvector, suggesting a strong common signal associated with climatic factors.

The results show that *P. halepensis* growth is mainly controlled by precipitation. Previous studies reported that growth of Aleppo pine is controlled by soil water availability (Rathgeber et al. 2005) and precipitation is the main factor influencing tree growth of pine species in semiarid Mediterranean regions (Raventós et al. 2001). Winter previous to the growing season and current year spring precipitation are positively correlated with tree-ring growth. Similar results were found in the Attica basin (Greece) (Papadopoulos et al. 2008). Other Mediterranean pine species support this conclusion: growth of *Pinus pinea* in a dry Mediterranean area in Portugal, *Pinus pinaster* in central Spain and *Pinus sylvestris* at its southern distribution limits were positively correlated with rainfall (Campelo et al. 2006; Bogino & Bravo 2008; Bogino et al. 2009). Growth of *Pinus nigra* in central Spain and *Pinus pinaster* in Portugal were mainly influenced by May precipitation (Martin-Benito et al. 2008; Vieira et al. 2009).

We found a higher tendency in young stands for developing IADFs. These results corroborate previous dendroecological studies, which suggested that IADFs were more frequent in younger tree rings (Rigling et al. 2001; Villalba & Veblen 1994; Vieira et al. 2009; Bogino & Bravo 2009). This could be due to a faster response of young trees to changing factors (Villalba & Veblen 1994) and/or to a longer growing season of young trees (Rossi et al. 2008). Since young trees have a different response to environmental factors than old trees, the incorporation of age-dependent differences on the appearance of special ring features such as IADFs and their association to climatic variables provides a useful proxy for complementing dendroclimatological data. In addition, these parameters can support to predict differences on how young and old trees react to climate change. As it was previously reported (Bogino & Bravo 2009) higher IADF frequencies occurred in the most recent fifty years. The increase in drought events in the Iberian Peninsula (IPCC 2007) may explain the higher IADF frequency during this period.

The occurrence of IADFs in *Pinus halepensis* was positively correlated with precipitation in December and April and negatively correlated with precipitation in July. These results are consistent with those of previous studies in *Pinus pinaster* in central Spain, where IADFs were mainly correlated with rainfall pulses in late winter and spring (Bogino & Bravo 2009). IADFs correlated positively with precipitation events early in summer following a water deficit early in the growing season in *Pinus pinea* in southern Portugal (Campelo et al. 2006), which is consistent with the present results that showed precipitation in July to have a negative effect on IADFs. Favourable climatic conditions in winter and spring as well as water deficits early in the growing season followed by rainfall indicate an increase in the probability of the occurrence of IADFs. This corroborates that growth may temporarily stop, but is always ready to resume activity as soon as climatic conditions become favourable.

Winter precipitation preceding the formation period of the tree-rings as well as the spring rainfall at the beginning of the growing season play a prevailing role to the development of wider tree rings in P. halepensis (Papadopoulos et al. 2008). These climatic conditions also appear as favourable conditions for the formation of IADFs in our study, supporting previous findings that showned IADFs to be more frequent in wider tree-rings (Vieira et al. 2009; Rigling et al. 2001; Villalba & Velben 1994).

Conclusions

Pinus halepensis is an accurate species for tree-ring analysis with good correlations between trees growing at the same site and a clear response to environmental factors. Suppressed trees showed higher sensitivity than dominant trees, with greater growth rates during favourable years except for Ampudia, where dominant trees showed higher sensitivity than suppressed trees. Precipitation was the main factor influencing tree-ring growth. IADFs were more frequent in young than in old stands with no clear differences according to crown classes. A higher frequency in IADFs occurred in the last fifty years, which coincides with the increase in drought events in the Iberian Peninsula. The probability model used, showed that high precipitation in spring and winter indicates an increase in the probability of the occurrence of IADFs, while high precipitation in July indicates a decrease in the probability of the occurrence of IADFs in Aleppo pine trees growing under Mediterranean climate conditions.

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Enigmatic cycles detected in subfossil and modern bog-pine chronologies from southern Sweden

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Introduction

Bog trees are commonly regarded as unsuitable high-resolution climate indicators, since their annual growth may be affected by ontogeny and other dynamics in the peat which are not directly related to climate or by processes that are related to climate over multiple years. Consequently, direct correlations between ring-widths of bog pines and observed climate may be weak or in some cases non-existent. However, bog-pine tree-ring records may provide valuable palaeoclimate information, especially on decadal and longer timescales (Eckstein et al. 2009, 2010, Edvardsson et al. in review), although further research is needed to fully understand the effects of climate change.

Growth dynamics of bog trees are highly dependent on the depth and variability of the water table beneath their root systems (Boogie 1972, Eckstein et al. 2009). Increased precipitation in areas where the groundwater table is close to the surface may result in a shallower unsaturated zone, which often leads to growth reductions (Gunnarson 1999). Similarly, a lowering of the water table may lead to increased growth (Linderholm 1999). It can therefore be assumed that hydrology is a major factor controlling tree growth on peat bogs, and that regional phases of synchronous growth depression/increase may indicate periods of wetter/drier conditions associated with large-scale climate dynamics (Leuschner et al. 2002, Eckstein et al. 2009). It has been suggested that variations in the solar and lunar cycles influence hydrology (Tomasino & Valle 2000), and therefore also groundwater levels in peat bogs. Thus, it may be possible that influences of e.g. variations in the sunspot cycle can be found in peat-bog tree-ring data.

There are several ways to advance our knowledge of factors affecting growth variability of bog trees, e.g. to combine dendroclimatology with peat strafigraphic investigations based on bulk density and macrofossil content of the peat or stable isotope analysis. In this study pine ring-width chronologies from seven peat bogs in southern Sweden were subjected to spectral and wavelet analyses to identify potential occurrences of periodicities in the tree-ring data during three separate parts the Holocene.

Material and methods

Site description and fieldwork

All analyses were performed on chronologies developed from Scots pine (*Pinus sylvestris*), a common species on South Swedish peat bogs (Zackrisson 1977), which normally invades open and exposed sites after disturbances like drainage, deforestation or fire (Freléchoux et al. 2000, Eckstein et al. 2010). The pine material was collected at seven South Swedish peat bogs (Fig. 1). The subfossil material originates from three bogs used for peat harvesting; Viss mosse, Hällarydsmossen (Edvardsson et al. in review) and Åbuamossen (Edvardsson 2010). In total 337 cross-sections from subfossil pine trees were collected with a chainsaw; 80 from Viss mosse, 128 from Åbuamossen and 129 from Hällarydsmossen. The modern material originates from four raised bogs with limited anthropogenic impact; Store mosse (Edvardsson unpublished data), Anebymossen, Hanvedsmossen and Bredmossen (Linderholm et al. 2002). During fieldwork at Store mosse 35 pine trees growing on peat exceeding 2 m in thickness were sampled with two cores per tree. The material from Anebymossen, Hanvedsmossen and Bredmossen has previously been described by Linderholm et al (2002).

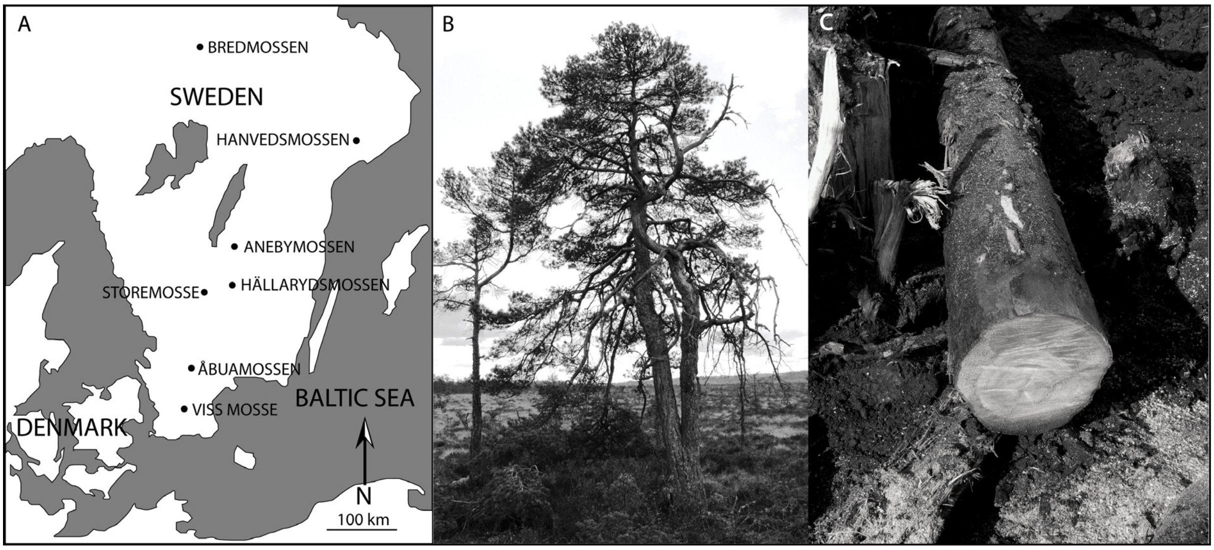

Figure 1: (A) The seven South Swedish peat bogs investigated. (B) Pine tree growing on Store mosse. (C) Subfossil pine tree from Viss mosse, which grew during the period 5077-4970 BC (Edvardsson et al. in review).

Data analysis

Annual ring-widths from each sampled tree were measured with a precision of 0.01 mm, using standard dendrochronological equipment (Schweingruber 1988). Measurements were performed using the CATRAS software (Aniol 1983). In order to detect missing or wedging rings and possible measuring errors, at least two radii or cores, separated by 90° or more, were measured for each tree. Averaged ring-width series from individual trees were thereafter combined into site records (master chronologies) and used in the further analysis. Assessments of the cross-dating and measurement quality, as well as the strength of the master chronologies, were performed with the COFECHA software (Holmes 1983).

One chronology from each site was developed (Tab. 1). Due to wide age distributions, only 259 of the 337 collected subfossil samples could be used for the chronologies, whereas almost all modern samples could be used. The ring-width records from Viss mosse and Hällarydsmossen were assigned calendar-age intervals based on cross-dating against German bog-pine chronologies (Edvardsson et al. in review), whereas the record from Åbuamossen (Edvardsson 2010) was dated with radiocarbon. Wiggle matching (Blaauw et al. 2003) against the IntCal04 radiocarbon calibration dataset (Reimer et al. 2004) was performed to improve the accuracy. The analysed chronologies cover 2680 years of the Holocene, and the material was divided into three separate periods, two based on subfossil material covering the periods 5219-3728 BC (Edvardsson et al. in review) and 2172-1204±9 BC (Edvardsson 2010), and one with modern material covering the period 1789-2008 AD (Linderholm et al. 2002, Edvardsson unpublished data). Standardization, also referred to as detrending, is a procedure which removes non-climatic trends related to e.g. age, geometry and height within the stem (Fritts 1976, Cook & Kairiukstis 1990) A flexible standardization method was applied to all individual ring-width series in order to remove effects of anomalously narrow rings during the first and last decades of growth, a growth trend observed especially on several of the subfossil trees. All ring-width series were standardized with a 67% spline with the ARSTAN software (Holmes et al. 1986). The expressed population signal (EPS) is a commonly used guide for quality tests of tree-ring datasets and evaluations of the reliable length of chronologies (Wigley et al. 1984). The ARSTAN software (Holmes et al. 1986) was used to calculate lengths of periods with EPS above the threshold value 0.85 (Wigley et al. 1984).

Table 1: Bog-pine chronologies used for spectral and wavelet analyses. The table shows site names, number of trees used in each chronology, lengths of chronologies, intercorrelations of series (r), periods with EPS above 0.85, total age spans of the respective chronologies and average ring widths (RW).

Site	No. of trees	No. of years	*r*	No. of years with EPS>0.85	Age spans	Average RW (mm)
Viss mosse	44	646	0.531	424	5219-4574 BC	1.00
Hällarydsmossen	117	1112	0.562	964	4839-3728 BC	0.74
Åbuamossen	98	969	0.526	858	2172-1204±9 BC*	0.89
Store mosse	35	159	0.534	97	1849-2008	0.70
Anebymossen	21	150	0.539	118	1846-1996	0.65
Hanvedsmossen	23	196	0.614	186	1800-1996	0.63
Bredmossen	21	208	0.632	191	1789-1997	0.44

**Uncertainty due to radiocarbon dating.*

To assess possible periodicities in the tree-ring data, spectral analysis was performed on each chronology, using a range of different spectral analysis models. The results shown and discussed below were calculated using a Tukey-Hanning window (Blackman & Tukey 1958). Wavelet analysis was also performed to visualize the temporal stability of the detected cycles over the time-span of each chronology. The Sysat software package Autosignal 1.7 was used for both spectral and wavelet analyses. Each chronology was studied separately in its total length and for the period with EPS values above 0.85. The three chronologies developed from subfossil material, spanning between 646 and 1112 years, were also divided into 300-year sequences that underwent identical analyses as the complete chronologies. These analyses were made in order to assess whether detected cycles occurred temporary or remained stable over time.

Results

Spectral analysis

Highly significant ($p<0.01$) cycles of c. 13, 15, 31, 57 and 62 years were found (Fig. 2). Also cycles of c. 14, 18, 21, 31 and 62 years with a significance of $p<0.1$ were detected.

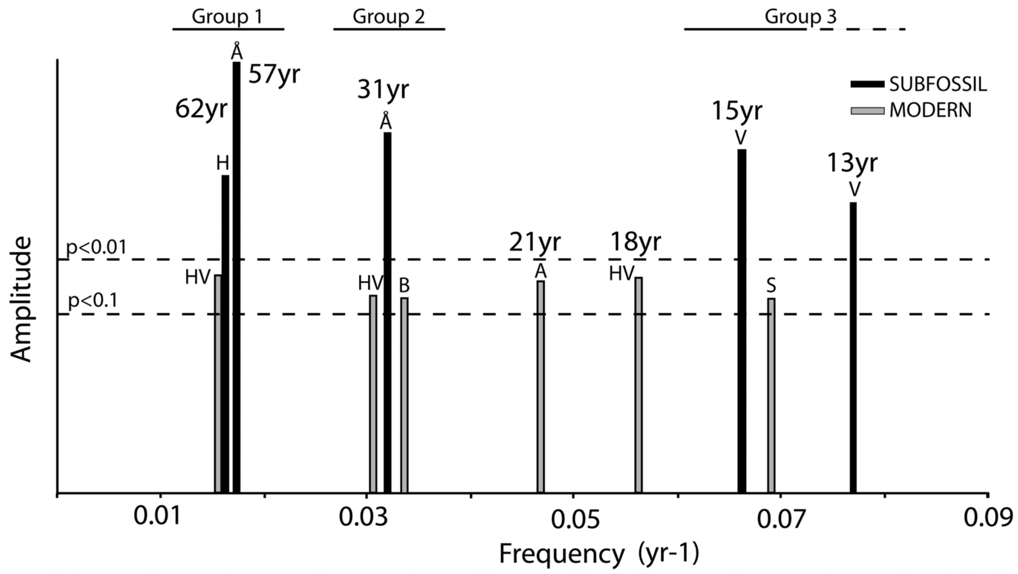

Figure 2: Comparison between cycles detected in the subfossil (black lines) and the modern (grey lines) ring-width chronologies. Lengths of the cycles in calendar years (yr) are shown above the lines. Each site is represented by letter/letters, V (Viss mosse), H (Hällarydsmossen), Å (Åbuamossen), S (Store mosse), A (Anebymossen), HV (Hanvedsmossen) and B (Bredmossen).

The cycles detected in the subfossil ring-width chronologies reached higher significance levels (five cycles with p<0.01) than those found in the modern chronologies (six cycles with significance level p<0.1 and no cycles reaching the highest significance level p<0.01).

Wavelet analysis

The c. 13- and the c. 15-year cycles detected in the Viss mosse record were seemingly stable over time and present during the full 646-year span of the chronology (Fig. 3).

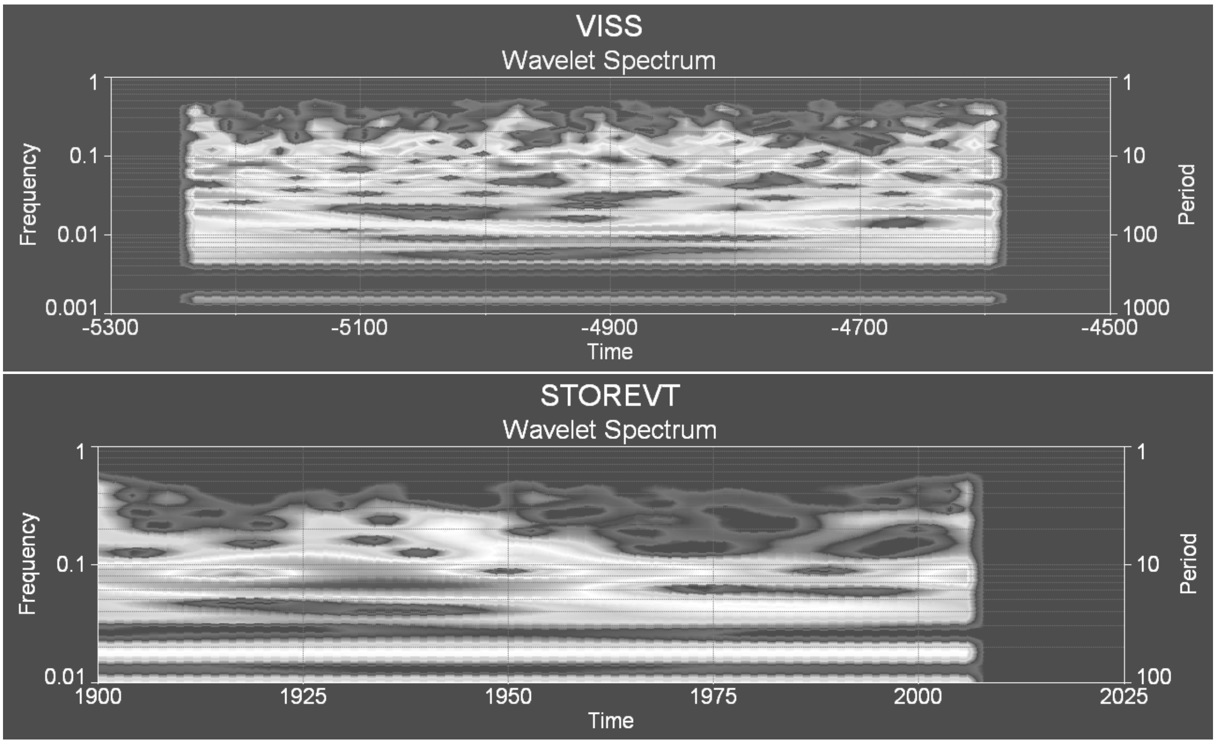

Figure 3: Upper panel: wavelet analysis of the Viss mosse ring-width chronology. The detected c. 13- and 15-year cycles appear to be present during most of the 646-year period. Also cycles between 50 and 80 years are present. However, these cycles have lower significance levels as they do not appear in the spectral analysis. Lower panel: wavelet analysis of the Store mosse ring-width chronology. Most cycles detected in the modern chronologies are not stable over time. For example, the cycles in the Store mosse chronology become markedly weaker between 1950 and 1975.

Similarly, the c. 62-year cycle in the Hällarydsmossen chronology is present during most of its 1112-year age span. However, the observed cycles in the 969-year long Åbuamossen chronology, of which the c. 31- and the c. 57-year cycles were the most significant, were not temporally stable. Moreover, the cycles detected in the four modern chronologies from Store mosse, Anebymossen, Hanvedsmossen and Bredmossen (Fig. 3) were not as robust or significant as those detected in the subfossil material.

Discussion

Several highly significant cycles were found, with cycles of c. 15, 30 and 60 years more frequently encountered (Fig. 2). These cycles may be associated with solar activity (e.g. sunspot variability), large-scale circulation of the North Atlantic Ocean and the atmosphere, precipitation cycles, or related to internal hydrological dynamics of the peat bogs. Groundwater fluctuations in peat deposits are the predominant growth-controlling factor for bog-tree growth (Boggie 1972), and as solar and lunar cycles affect groundwater levels, such planetary cycles may be encountered in ring-width chronologies from bog trees. However, the 11- and 22-year sunspot cycles were weak to absent in the records. A c. 11-year cycle was detected in the chronology from Viss mosse, but excluded as the significance level only reached $p<0.5$. The c. 21-year cycle detected in the Anebymossen chronology (Fig. 2) may be a solar cycle and the c. 18-year cycle detected in the Hanvedsmossen chronology (Fig. 2) may be related to lunar cyclisity. Yndestad (2006) linked an 18-20 year North Atlantic Oscillation (NAO) cycle to the 18.6-year lunar nodal cycle (O'Brien & Currie 1993). Both lunar cycles and atmospheric circulation indeces are believed to affect humidity and groundwater levels in peat bogs and can therefore be assumed to also affect peatland tree growth.

Similarities between cycles detected in modern and subfossil chronologies

When the material was divided into subfossil and modern chronologies (Fig. 2), three groups with similar common cycles were detected. Cycles around 60 years (Group 1) were detected in the chronologies from Hällarydsmossen, Åbuamossen and Hanvedsmossen. Multi-decadal variability connected to long-term changes in sea-surface temperature with a period of 62 years has been identified by e.g. Fischer & Mieding (2005). The 60-62 year cycle (Group 1), which is observed with different significance level in several chronologies, could therefore be related to internal dynamics of the climate system, such as the meridional overturning of the North Atlantic and/or the Atlantic Multidecadal Oscillation.

A second set of significant cycles (Group 2) clustered around a period of c. 30 years. These cycles were seen in the Åbuamossen, Hanvedsmossen and Bredmossen chronologies. The c. 30-year cycles are somewhat enigmatic, but may be related to previously described climate- and hydrology-related phenomena. An Atlantic Ocean oscillation cycle of c. 30 years that supports a coupled atmosphere-ocean mode was described by Justino & Peltier (2005). Moreover, a highly significant but puzzling c. 30-year cycle found in coral records was linked to a possible mixture of multiple solar cycles (3 times 11 years) and the NAO (4 times 7.7 years), amplified by e.g. changes in the polar front and North Sea salinity (Berger et al. 2002). Also, a 30-year sea-level cycle has been detected in the Finish Gulf and the Baltic Sea, and is significantly linked to the NAO (Johansson et al. 2001). It is difficult to judge to what extent these internal and external forcings have affected growth dynamics of pine trees on the South Swedish raised bogs as reflected by Group 2 cyclicity.

Finally, cycles of c. 15 years were detected in the Viss mosse and Store mosse chronologies (Group 3). Temperature variability observed in Norway identifies periods of warming and cooling in the entire northern North Atlantic with a cyclicity of c. 15 years (Yndestad 2006). Moron et al. (1998) described a 13- to 15-year oscillation cycle in North Atlantic sea-surface temperature, which can bee seen as a seesaw pattern between the Gulf Stream region and the North Atlantic drift. The 13-year cycle detected in the Viss mosse chronology may also be included in Group 3 as the cyclicity described by Moron et al (1998) ranges between 13 and 15 years. However, the highly significant 13-year cycle may also be linked to a 9-13 year periodicity in solar irradiance, which is thought to influence global sea-surface temperatures (White et al. 1997). In turn, these variations in sea surface temperature may affect precipitation patterns and humidity over land, which could potentially provide impacts on tree-growth patterns on raised bogs at mid to high latitudes.

Differences between modern and subfossil chronologies

The spectral and wavelet analyses also revealed some clear differences between the modern and subfossil bog-pines chronologies. The significance levels of cycles in the subfossil material were in general higher (five cycles above $p<0.01$ significance), than those identified in the modern material (six cycles above the $p<0.1$ significance level) and more stable through time. There are several likely reasons behind these differences. The climate of southern Sweden during the mid-Holocene was warmer and drier than at present (Jessen et al. 2005, Seppä et al. 2005), which probably created more favourable growth conditions for bog pines at that time. In addition, increasing anthropogenic impact on modern bog surfaces during the last c. 4000 years (Linderholm & Leine 2004), e.g. ditching and peat cutting, has most likely had an effect on bog pine growth, which complicates comparison between populations of widely different ages. The shorter time series available in the modern material also have to be taken into account. Consequently, differences in population dynamics and growth variability between living and subfossil trees are to be expected, and potentially associated differences in cyclicity should be interpreted with caution.

Conclusions

Consistent cycles of c. 60, 30 and 15 years in both modern and subfossil tree-ring chronologies from bog pines at several sites in southern Sweden may indicate coherent responses of tree populations to large-scale climate variability throughout the mid- and late Holocene. The nature of these cycles is still unclear, but external forcings mediated by atmospheric circulation dynamics in the North Atlantic region may be involved. Cycles may also be related to internal hydrological dynamics of the individual peat deposits. The low significance of most cycles observed in the modern material is likely due to relatively short time series and anthropogenic impact. Several questions remain regarding bog trees as climate indicators, and climate reconstructions based on subfossil material must rely on solid knowledge of local and regional factors controlling bog tree growth. However, more detailed analyses of growth dynamics of subfossil bog-pine populations may lead to increased understanding of hydrological variability and change during the Holocene.

Acknowledgements

We are grateful to Hans Linderson, Mats Rundgren and Hanns Hubert Leuschner for interesting discussions on pine trees and bog dynamics. This research was partly funded by the Crafoord Foundation, Stiftelsen Anna och Gunnar Vidfelts fond för biologisk forskning and Johan Cristian Mobergs resestipendiefond.

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The potential of the dwarf shrub *Betula nana* L. as a climate indicator above the tree line in the southern Norwegian Scandes

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Introduction

At higher latitudes and in the alpine zone of mountain areas, dwarf shrubs represent a potential complement to dendroecological investigations of trees (Bär et al. 2008, Hallinger 2008, Schweingruber & Poschlod 2005). Particularly with regard to the reactions of alpine ecosystems to climate change, dwarf shrubs represent promising environmental indicators (Bär et al. 2007). Schweingruber & Poschlod (2005) already showed that various dwarf shrub species are suitable for dendroecological analyses. Especially, the dwarf birch (*Betula nana* L.) is an interesting species because it is part of a group of closely related species with a circumpolar distribution (Heß et al. 1967). Hence, we tried to enlarge the knowledge about the dendroecological potential of dwarf shrubs with special focus on *Betula nana*, especially concerning dendroclimatology. Growing near to the ground, dwarf shrubs are influenced by varying local climate conditions depending on the micro-topography (Gjærevoll 1956, Moen 1999, Löffler 2005). Therefore we analysed the effect of these micro-topographical differences on ring width, especially regarding the snow distribution.

Material and methods

The research area is located at Filefjell in the central southern Norwegian Scandes (61° 9,901’ N; 8° 6,235’ E). Mean annual precipitation at the study site is 770 mm and mean annual temperature is -0.4 °C. Mountain birch (*Betula pubescens ssp. czerepanovii*) forest ranges up to 1060 m a.s.l. forming the upper tree line. Above it lays the lower alpine zone dominated by a dwarf shrub heath in which dwarf birch (*Betula nana* L.) is a main constituent.

In the fine-scale alpine topography of a north-facing slope in the lower alpine zone (1125 m a.s.l.), an area including a snow depth gradient between two small ridges crossing a depression was chosen as the study site. The vegetation was mapped along two orthogonal transects. The distinct zonation of the vegetation indicated a strong influence of a characteristic alpine snow-cover gradient on plant distribution. In the following, the study site will be referred to snow-bed.

We collected 25 samples of *Betula nana* along the snow depth gradient to analyse the influence of snow distribution on ring width. The samples were taken as whole individuals cut at the soil surface.

To establish a reference ring width chronology, we collected increment cores from birch trees (*Betula pubescens ssp. czerepanovii*) from the same slope (990-1060 m a.s.l.). Four radii per tree were taken at breast height from 20 trees. We measured ring width with LINTAB-station and used TSAP-Win (version 0.53, Rinn 2003) for synchronisation of the ring width curves. In order to measure ring width of *Betula nana*, thin sections of the stems were prepared with a sledge microtome. The utilization of the whole stem section is necessary for being able to search for wedging rings and to synchronise the ring width curves of the radii (Bär et al. 2006). The thin sections were stained with solutions of safranin red and astra blue (Etzold 1983) and photographed sequentially with a microscope camera. The individual segments were then merged semi-automatically to get a complete picture of each thin section. Finally, ring widths were measured from digital photos with the software LignoVision (version 1.37, Rinn 2006).

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Different dwarf shrub studies already demonstrated the problem of missing or wedging rings (e.g. Bär et al. 2007, Zalatan & Gajewski 2006, Petersdorf 1996). Therefore, we prepared two or three micro sections near the stem basis per sample and compared the ring width curves with the reference tree-ring chronology. In order to obtain complete ring width series of *Betula nana* and to synchronise them, it was not necessary to apply the complete serial-sectioning-method according to Kolishchuk (1990), but two or three thin sections near the root collar turned out to be sufficient. Although *Betula nana* exhibited many wedging rings, most of the ring width curves could be synchronised and 24 of 25 dwarf birch samples could be used to construct a chronology that was established in three steps: I) Ring width measurement along several (two to five) radii and establishment of mean curves for each thin section. II) Averaging thin section mean curves into specimen mean curves. III) Chronology establishment from several specimens' mean curves.

To analyse the influence of the micro-topography on ring widths of *Betula nana*, we built two dwarf birch local chronologies from the ridges and from the inner part of the depression, respectively. Since both chronologies were very similar, we constructed a master chronology from all dwarf shrubs irrespective of topographic location. To remove age-related growth trends, the specimen mean curves of *Betula nana* and *Betula pubescens ssp. czerepanovii* were both detrended using a cubic smoothing spline filter which removed 50% of the variance of frequencies with two thirds of the series length in ARSTAN (version 41d, Cook 1985). The standardised chronologies were then used for climate-growth analysis.

Climate data from different locations were used. Precipitation data from the hydrological measurement station Maristova were provided by the Norwegian Meteorological Institute. This station is located 806 m a.s.l. at a distance of 8 km to the study area. There is no climate station close to the study area measuring temperature continuously. Therefore temperature data for the study site were extrapolated from measured temperature data (1967-1974) of the nearby climate station Varden (Norwegian Meteorological Institute) and NCEP/NCAR reanalysis data (NOAA National Center for Environmental Prediction). To analyse climate-growth-relationships and to detect the main factors influencing the ring widths of *Betula nana,* linear correlations between the ring width indices and monthly mean temperature and precipitation were calculated using the software DENDROCLIM2002 (Biondi & Waikul 2004). Correlations were computed for the period from May of the previous year to September of the current year.

In this study we also calculated the pointer years according to Cropper (1979) for *Betula nana* and compared them to the mean July temperature.

Results

The two dwarf birch chronologies from the ridges and the depression of the snow-bed show high similarity (Fig. 1). The gleichlaeufigkeit between both chronologies is 73% ($p<0.001$), indicating that the dwarf birches from all micro-topographical locations are influenced by the same climatic factors. Individuals from the ridges were in general considerably older than the individuals growing in the depression.

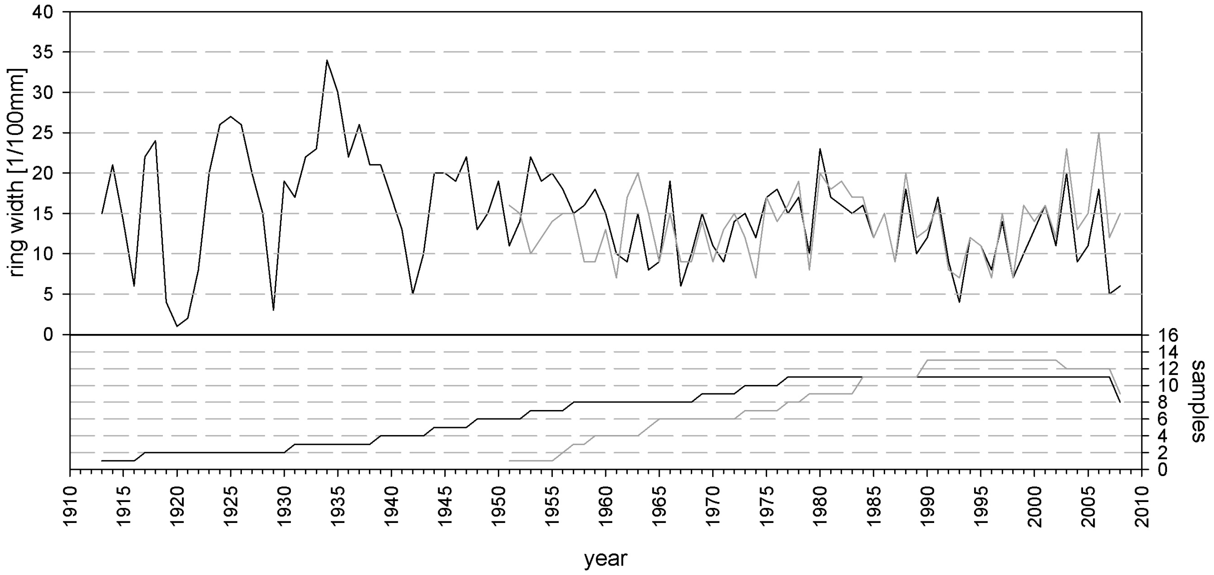

Figure 1: Betula nana raw value chronologies from the ridges (black lines) and the inner part of the snow-bed (grey lines).

We compared the final index chronology of *Betula nana* to the reference chronology of *Betula pubescens ssp. czerepanovii* (Fig. 2). Although both species belong to different life forms, the gleichlaeufigkeit between their chronologies is 68% (p<0.001). The high similarity indicates that growth-ring variations of *Betula nana* and *Betula pubescens ssp. czerepanovii* contain a common climate signal.

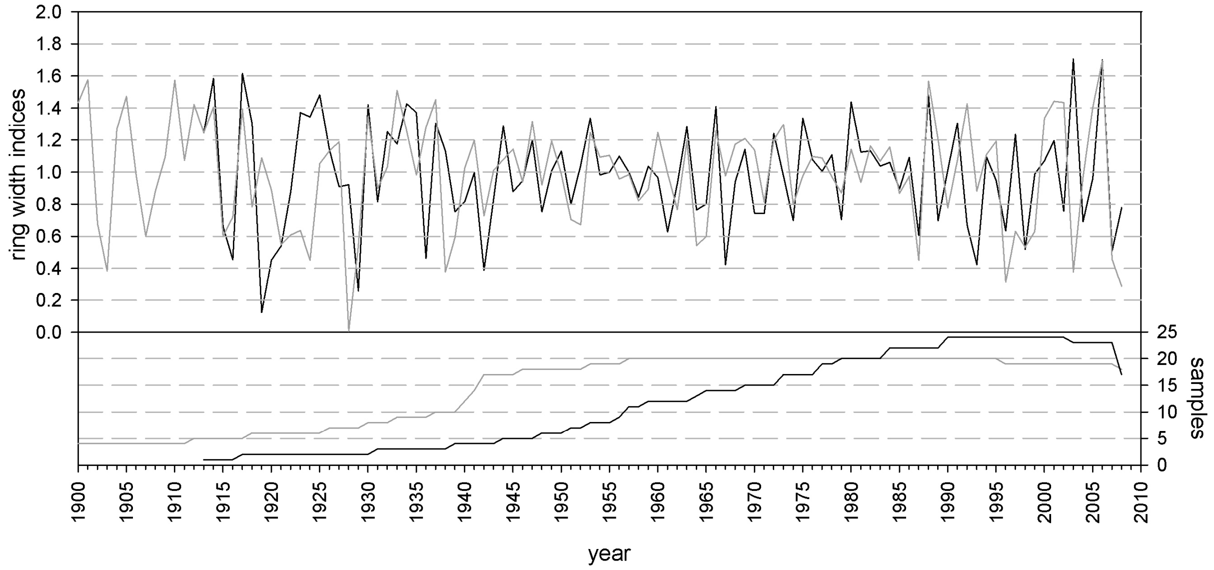

Figure 2: Chronologies of Betula nana (black lines) and Betula pubescens ssp. czerepanovii (grey lines).

The correlation between the *Betula nana* ring width indices and monthly mean temperatures shows high positive values during the vegetation period (July, August) of the current year (Fig. 3). This indicates that dwarf birch growth is mainly influenced by summer temperature (particularly July). Precipitation has only low impact on ring width variations, as indicated by insignificant correlation coefficients between ring widths and precipitation during the vegetation period.

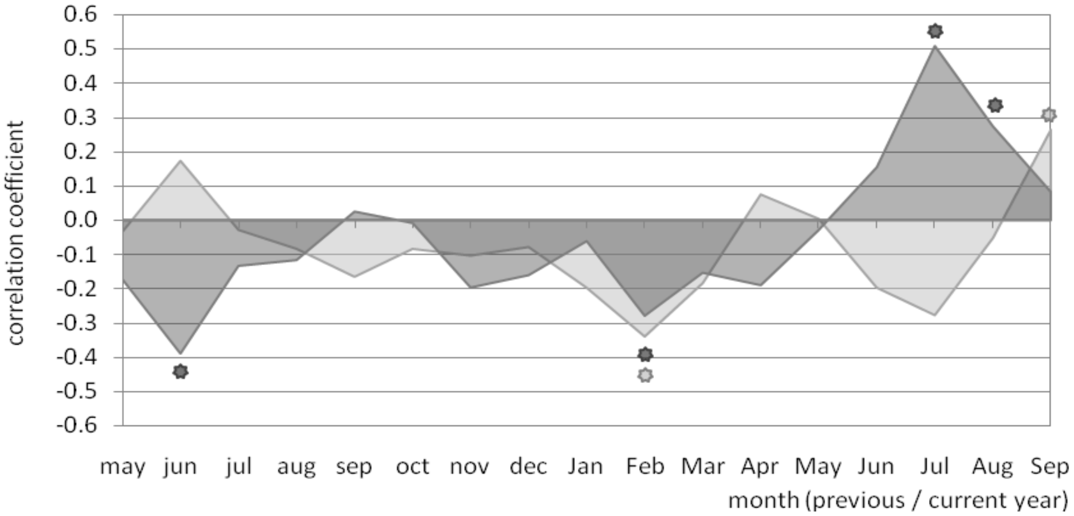

Figure 3: Correlation between ring width indices of Betula nana with monthly mean temperatures and precipitation data (1951-2008). Light grey indicates correlation with precipitation, dark grey with temperature. Stars indicate significant values ($p < 0.05$).

The strong influence of July temperature on ring widths is also seen in years with exceptional growth of *Betula nana*. Figure 4 compares pointer years of the *Betula nana* chronology according to Cropper (1979) and deviations of July temperatures from the long term mean. There are years where the data series do not conform to each other, e.g. in 1955, when July temperature was above average, but did not have a positive effect on ring widths, and in 1964, when the cold climate was not reflected by a negative pointer year. Yet, in the periods from 1970 to 1980 as well as from 1988 to 2006, the agreement of pointer years and mean temperature of July is high.

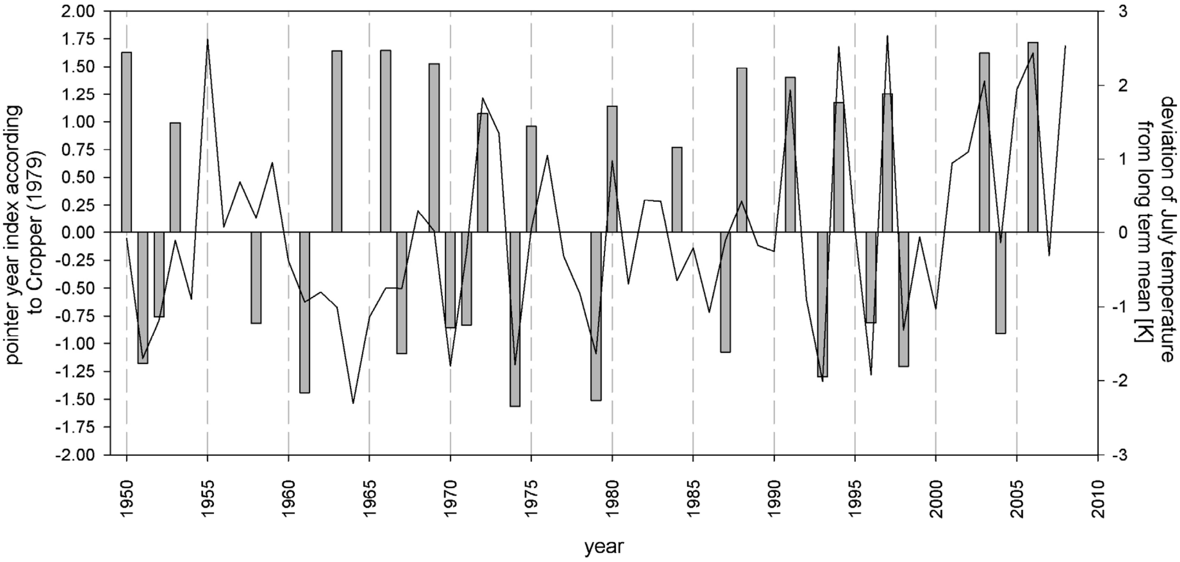

Figure 4: Pointer years of Betula nana according to Cropper (1979) (bars) and deviation of July temperatures from the long term mean (line).

Discussion and conclusions

The present study demonstrates the suitability of *Betula nana* for dendroecological analysis. Although wedging rings occur repeatedly in the stem discs, ring widths could be measured. Individual ring width series were successfully synchronised and chronologies were established.

The high similarity between the *Betula nana* chronology and the reference chronology of the tree species *Betula pubescens ssp. czerepanovii* suggests that ring width variations of *Betula nana* contain a climatic signal.

Ring widths of *Betula nana* are strongly influenced by summer temperature, mainly by temperature of July and August. The ring widths of the tree birches were also positively correlated with summer temperature ($r_{May} = 0.27$; $r_{June} = 0.25$; $r_{July} = 0.34$, all significant on the 95% level, study period 1951-2007), indicating that both species are mainly influenced by summer temperature. Because of the strong influence of mean July temperature, *Betula nana* can be used as an indicator for summer temperature in alpine habitats beyond the upper tree line. Similar results were described in other dwarf shrub studies. Bär et al. (2007) demonstrated the high influence of summer temperature on ring width of *Empetrum hermaphroditum*. July temperature is most important, followed by the temperatures of August and June. Hallinger (2008) reported positive correlations between ring width curves of *Juniperus nana* and the temperatures of June and July.

The comparison between the *Betula nana* chronologies from the ridges and the inner part of the snow-bed revealed that micro-topography does not significantly alter the climate response of *Betula nana*. Yet, in the age of the dwarf birches from the different locations a difference is detectable. Bär et al. (2008) analysed the impact of topography on ring widths of *Empetrum hermaphroditum* by comparing different microsites. Annual growth-ring increments were slightly modified by different microclimatic conditions, but nevertheless the common growth pattern was reflected at all microsites.

Considering the distribution of *Betula nana*, the suitability of this dwarf shrub species offers new perspectives for dendroecological studies into arctic and alpine zones to enlarge our knowledge about climatic variations in these regions.

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