TRACE - Tree Rings in Archaeology, Climatology and Ecology

Holger Gärtner, Philippe P. Rozenberg, Olivier Bertel, Patricia Montes Duran, Ingo Heinrich, Gerhard Helle

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Volume 10

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Preface

The 10th TRACE conference (Tree Rings in Archaeology, Climatology and Ecology) was organized by the Institut National de la Recherche Agronomique (INRA) - Centre d'Orléans Unité Amélioration, Génétique et Physiologie Forestières, on May 11th – 14th 2011 in the "Muséum des Sciences Naturelles" in Orléans, France.

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.
More than 100 scientists working on tree-ring related topics participated conference, coming from Austria, Belgium, Canada, Czech Republic, France, Germany, Iran, Italy, Latvia, the Netherlands, Poland, Portugal, Romania, Russia, Spain and Switzerland, among which 65 students.

A total number of 43 oral and 36 poster presentations highlighted the various aspects of tree-ring research: Wood anatomy & seasonal dynamics, dendroecology & dendrogeomorphology, archaeology and climatology.
The conference days were opened by the inspiring presentations of three invited speakers.
Nicola Macchioni (IVALSA CNR, Florence, Italy) presented an integrated approach focusing on tree - rings and archaeological wood.
Hubert Morin (Université du Québec à Chicoutimi, Canada) presented the spatiotemporal dynamics of spruce budworm outbreaks in North-Eastern North America.
Ignacio García González (Universidad de Santiago de Compostela, Spain) presented a general introduction on earlywood anatomical features as a dendroecological tool for ring-porous trees.

This volume of TRACE Proceedings contains 16 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 2011
Rinntech (Germany), Regent Instruments Inc. (Canada), Labman Automation Ltd. (United Kingdom), Beta Analytic Limited (United Kingdom), Retsch (France), PerkinElmer (France), Kronofrance (France), Ville de saint-Cyr en Val, Ville d'Orléans, Conseil régional de la région Centre, and Institut National de la Recherche Agronomique (INRA)
for their financial support.

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Philippe Rozenberg
Patricia Montès
Olivier Bertel
Ingo Heinrich
Gerhard Helle

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SECTION 1

CLIMATOLOGY

Tracing responses to climate variability from stable isotopes in tree rings of *Anogeissus leiocarpus* and *Sclerocarya birrea* from the Sahel zone, Burkina Faso

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Introduction

Global climate change is expected to markedly affect plant growth and performance, and, as a consequence, the composition and spatial distribution of species in terrestrial ecosystems (IPCC 2007). Plants on the other hand show an integrated physiological and growth responses to the changes, hence, understanding the long term performance of plants under a changing climate is essential to evaluate their resilience to climate variability. However, precise palaeo-climate records, to trace the course of environmental and climatological fluctuations, from the tropics, notably from Africa, are still sorely lacking (Gebrekirstos 2009). Therefore, it is central to identify potential proxies that could provide empirical data regarding past climatic events and improve our knowledge about adaptation to climate changes.

Tree ring widths and stable isotopes in tree rings have been successfully used as climate proxies in temperate and boreal 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. 2009, Gebrekirstos et al. 2011a, Trouet et al. 2006, Fichtler et al. 2004, Wils et al. 2010). From the Sahel region in Burkina Faso, the current study area, Gebrekirstos et al (2011b) reported the potential of stable isotopes from tree rings of *Sclerocarya birrea* as a climate proxy. Based on the pilot results we further extended our research questions to address the following questions:

1) Are co-occurring species influenced by similar climate forcing?
2) Can we detect different environmental and climatic information from different species at a site?

In this paper we present preliminary comparisons of results from stable oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopes in tree rings of the co-occurring species *Sclerocarya birrea and Anogeissus leiocarpus* from the Sahel region in Burkina Faso as a climate proxy.

Methodology

Study site and climate

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 West African monsoon (WAM). Six samples of stem disks from the two studied species were collected from Sahel region in Burkina Faso (Tougouri), (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 $^{\circ}$C with the hottest months from March to May (about 40 $^{\circ}$C).
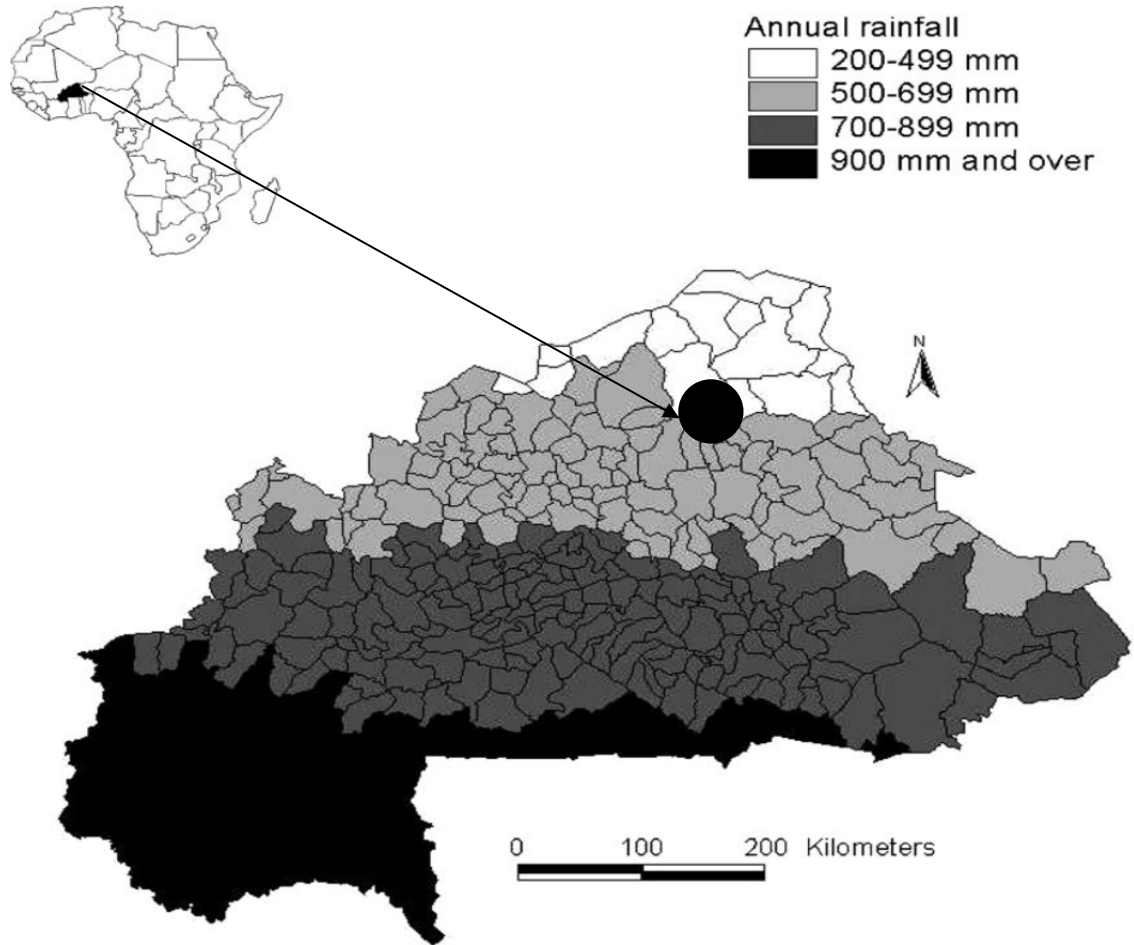
Figure 1: Location of the study area Burkina Faso in West Africa. The circle indicates the location of the study site (village Tougouri)
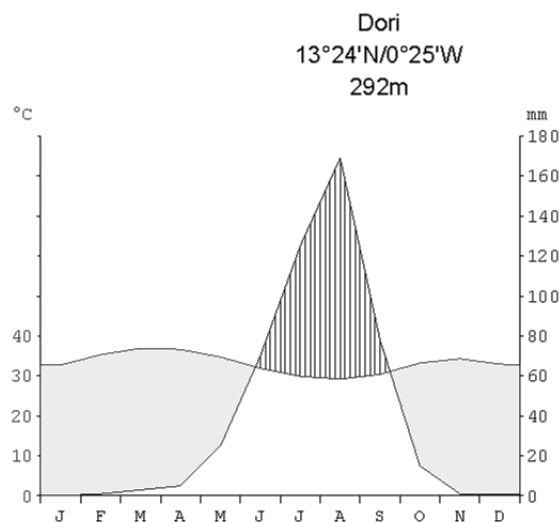
Figure 2: Climatic diagram from Dori station drawn according to Walter (1973). Rainfall (mm) and temperature (°C) data (1987–2007) were obtained from Burkina Faso Meteorological Agency.

Study species and measurement of stable isotopes

The study species belong to different functional traits. *Sclerocarya birrea* is a deciduous tree that belongs to the family Anacardiaceae, and grows to a height of about 20 m. It is widespread species throughout the semi-arid, deciduous savannas of much of sub-Saharan Africa. On the other hand, *Anogeissus leiocarpus* is a tall evergreen tree belongs to family combretaceae. Both species are important multipurpose species found in large parts of Africa. The fruits of *S. birrea are* used to produce the liquor called "Amarula" and the inner bark of *A. leiocarpus* is used for treatment of worms in human and animals.

For the $\delta^{13}C$ and $\delta^{18}O$ pilot measurements, we selected two stem disks from each species that had been dated using standard dendrochronological procedures. The $\delta^{13}C$ and $\delta^{18}O$ analyses were performed for each individual at one-year resolution from 1983 to 2007. We used bulk wood for this investigation. Powdered samples were produced from two to three radii of each tree using a drill width of 0.5 mm (Fig. 3). The powders of several drill holes per year 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. From each sample, 1 mg and 0.2 mg of powdered wood was used for the $\delta^{13}C$ and $\delta^{18}O$ 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 $\delta^{13}C$ series related to the decline in atmospheric $\delta^{13}C$ values was removed following the method described in Mc Carroll & Loader (2004). To determine the relation between the $\delta^{13}C$ and $\delta^{18}O$ values and climate variables, we used precipitation (monthly and annual), Palmer Drought Sensitivity Index (PDSI) and maximum temperature. 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.
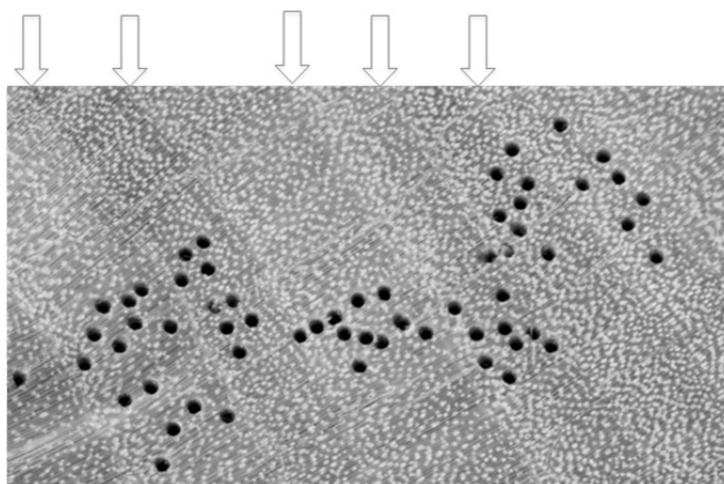
Figure 3: Cross-section of Anogeissus leiocarpus, arrows indicate annual growth boundaries black dots represent holes drilled for obtaining wood material for stable isotope analyses.

Results and Discussions

Formation of growth boundaries

Even though *A. leiocarpus* is an evergreen species, it forms distinct rings characterized by marginal parenchyma bands and density variations (Fig. 3). *S. birrea* forms distinct rings characterized by parenchyma bands (Gebrekirstos et al 2011). The study area is marked by uni-modal rainfall distribution and about eight months of dry season that triggers cambial dormancy in evergreen species and leaf shedding in the deciduous species, and, consequently, leads to

formation of annual growth boundaries. However, growth boundaries of the deciduous *S. birrea* are very distinct (Gebrekirstos et al 2011b) compared to growth boundaries of *A. leiocarpus*.

Inter annual $\delta^{13}C$ and $\delta^{18}O$ patterns

The preliminary results showed that the inter-annual patterns of $\delta^{13}C$ and $\delta^{18}O$ ratios in tree rings of *A. leiocarpus* and *S. birrea* are uniform between the two individual trees indicating that marked fluctuations in stable isotope ratios are synchronous between the species (Fig. 4 a and b). This is further confirmed by cross-correlation analyses of the species mean $\delta^{13}C$ series (r = 0.41) and $\delta^{18}O$ (r = 0.53). The similar pattern within and between $\delta^{13}C$ and $\delta^{18}O$ ratios indicate that external factors affected isotope fractionations in a similar way. 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.
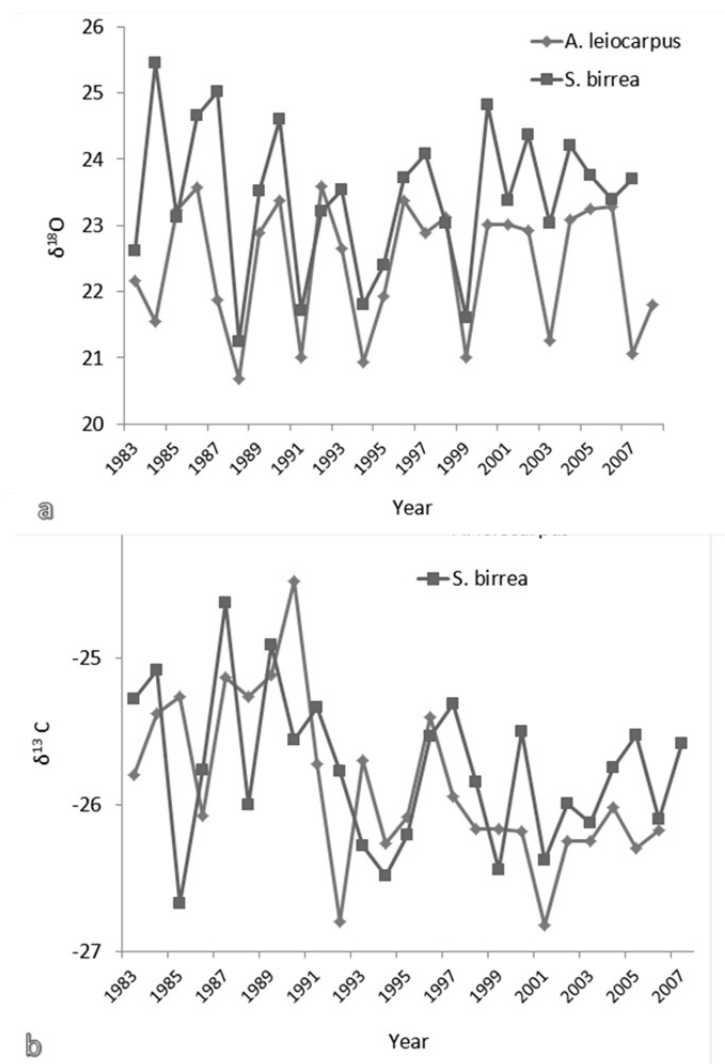
Figure 4: *Sclerocarya birrea* and *Anogeissus leiocarpus;* a) $\delta^{18}O$ and b) $\delta^{13}C$ patterns and correlations

$\delta^{13}C$, $\delta^{18}O$ and climate

Isotopic fractionations in both species are influenced by similar external forcing (Fig 5). In general, both $\delta^{13}C$ and $\delta^{18}O$ showed negative correlations with rainfall, and PDSI. In the contrary, they showed positive correlations with maximum temperature. Some of the relationships mentioned are explained by the covariance of some climatic factors, e.g. high rainfall would mean higher 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. 2009, 2011b, Wils et al 2010). Similarly, negative correlations with $\delta^{18}O$ also reflect that $\delta^{18}O$ in tree rings of *both species* records dry and moist years. Due to high evaporative demand in drier conditions there is a stronger enrichment of $\delta^{18}O$ both in soil and leaf water resulting in high concentration of $\delta^{18}O$ in wood formed in drought years. In contrast, depletion of the heavier isotope $\delta^{18}O$ indicates moist years.
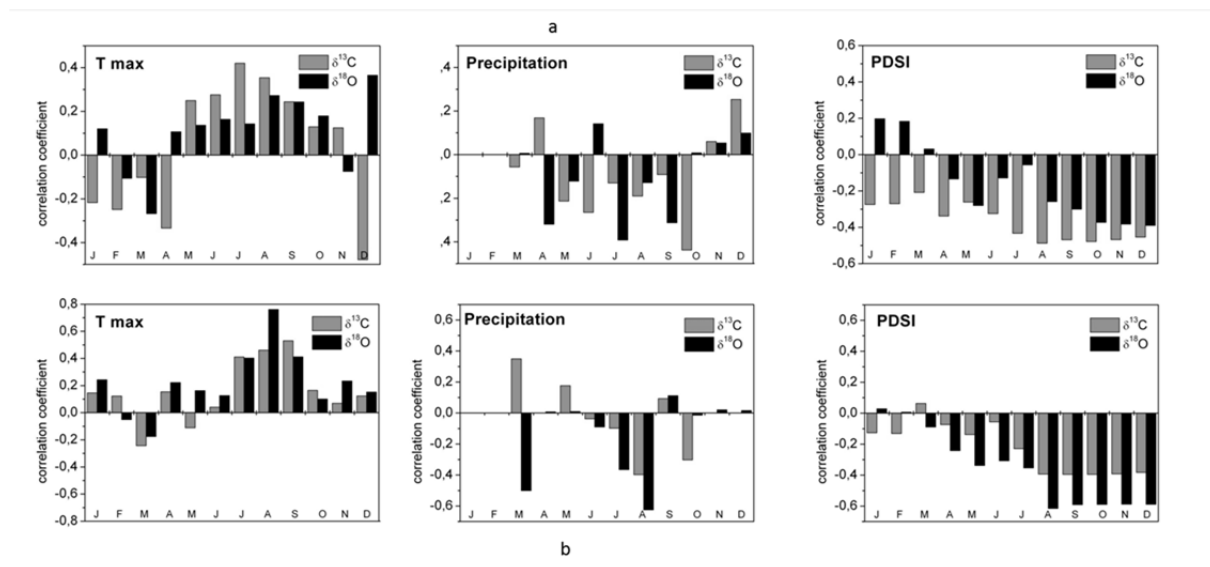
Figure 5: Correlation between $\delta^{13}C$ and $\delta^{18}O$ and climate parameters of a) *Anogeissus leiocarpus* b) *Sclerocarya birrea*

Species comparisons to climate variability

The $\delta^{13}C$ and $\delta^{18}O$ values of *A. leiocarpus* range from --23.66‰ to -26.82‰ and 24.5‰, 20.05‰, respectively, while *S. birrea* $\delta^{13}C$ and δ^{18} O values range from -24.6‰ to -26.7‰ and 25.45‰ to 21.24‰, respectively. In terms of $\delta^{13}C$ both species are in a similar range but the maximum and minimum $\delta^{18}O$ values of *S. birrea* are enriched by *about* 1.19‰. *A leiocarpus* $\delta^{13}C$ ratio showed a declining trend (R = 0.34) with time, but no declining trend was observed in $\delta^{13}C$ of *S. birrea.*

Although isotopic fractionations in both species are influenced by similar external forcing, *S birrea* is more sensitive to climate variability as indicated by the stronger correlations with climate parameters (Fig. 5). There are also differences in climatic signal strength between $\delta^{18}O$ and $\delta^{13}C$ between the species. $\delta^{13}C$ of *A. leiocarpus* showed stronger climatic response compared to its $\delta^{18}O$ signal (Fig. 5a). In the contrary, $\delta^{18}O$ of *S birrea* showed stronger response to the climate parameters compared to $\delta^{13}C$ (Fig. 5b). In fact a closer look at the variations of $\delta^{18}O$ in *A. leiocarpus* showed minimum inter-annual fluctuations, especially after 1999, compared to the marked inter-annual variations in *S. birrea*. Treydte et al. (2010) reported that $\delta^{18}O$ in tree rings primarily record the source water information. Hence, the stronger and higher level of statistical significance of $\delta^{18}O$ in *S birrea* with precipitation amount in the rainy season would reflect that the main source of water for the growth of *S. birrea* is soil water (Gebrekirstos et al 2011b). In contrast,

the weaker correlation and depleted minimum and maximum $\delta^{18}O$ values and less marked inter-annual variations of $\delta^{18}O$ in *A. leiocarpus* compared with *S. birrea* might indicate that it uses deeper soil water sources. Perhaps the declining trend in $\delta^{13}C$ for *A leiocarpus* could also be due to its better access to water with increasing rooting depth.

Outlook

The pilot measurements showed the potential of $\delta^{13}C$ *and* $\delta^{18}O$ in tree rings of *A. leiocarpus and S. birrea* as climate proxy. The good agreement between the two species is quite remarkable, although there are certain differences in their climate sensitivity. Sclerocarya birrea seems to be more sensitive to climate variability compared to *A. leiocarpus.* For *A. leiocarpus* $\delta^{13}C$ ratio showed stronger climatic signal, while for *S. birrea* $\delta^{18}O$ carried stronger climatic signal. In the future we intend to make comparisons based on measurements in the cellulose component to rule out the possibility of variation due to differences in wood constituents in the different species. Our ultimate objective is to develop longer tree ring chronologies from different agro- ecological zones influenced by different climate regimes to put the short instrumental record including the Sahel drought events into a longer term perspective.

Acknowledgments

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Increased sensitivity in ring width series of common beech after 1990 – climatic impact or normal patterns due to ageing?

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Motivation – problem situation

During the last three decades many beech stands in Germany show a conspicuous growth pattern (Beck 2009, 2011). Tree ring width series show a dramatic increase of sensitivity beginning in the 1980s. This changed growth pattern, compared to the period before 1980, may be associated with the increased number of years with an unfavourable climate, especially warm and dry summers. This pattern appears even more distinct if the series of ring width data are transformed into a series of basal area increment (BAI). For illustration, a typical example (beech sample plot Chorin, North-eastern German lowlands) is shown (Fig. 1 and 2).
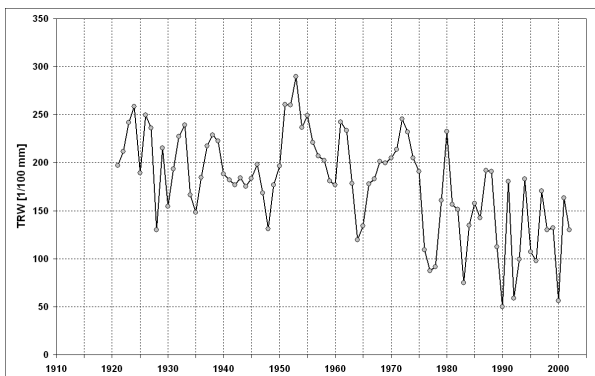
Figure 1: Course of mean radial increment
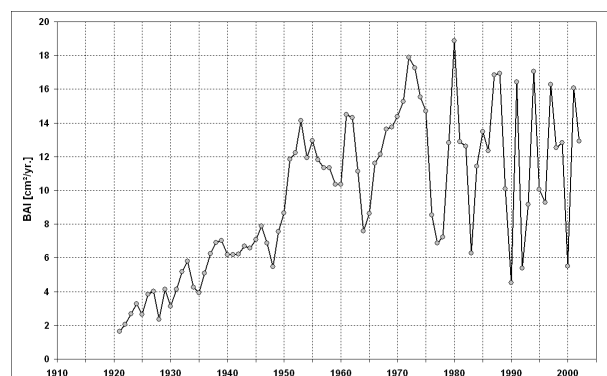
Figure 2: Course of basal area increment
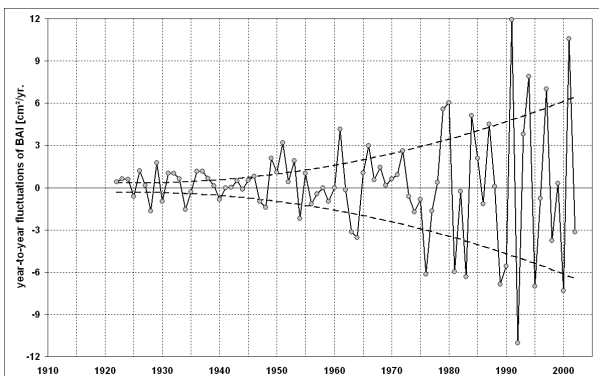
Figure 3: First order differences of BAI together with trend estimation
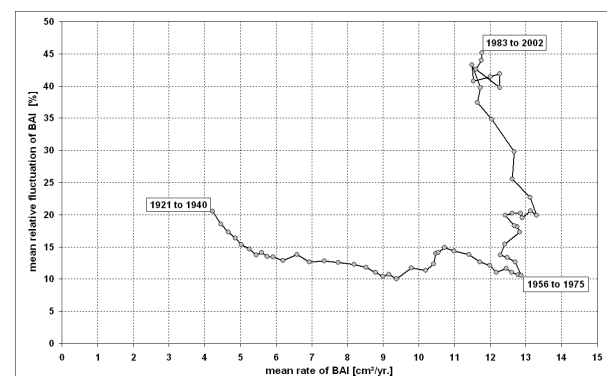
Figure 4: Relation between mean relative fluctuation of BAI and mean rate of BAI; calculations within moving time spans of 20 years

The course of BAI (Fig. 2) shows an additional change in trend within the 1970s. In order to evaluate these changes, first order differences of BAI were calculated and its temporal trend were estimated (Fig. 3). The non-linear increase of the year-to-year fluctuations suggests a really dramatic change and leads to the expectation of a collapse. On the other hand, there may be a dependence of the size of fluctuations from the size of the increment level itself. Therefore, mean rates of BAI as well as mean relative fluctuations of BAI were calculated within 20-year moving

windows. These two parameters were compared to detect temporal changes of their relationships (Fig. 4). Here, a clear temporal change is obvious. Up to the 1956 to 1975-interval the relative fluctuation declines slightly while mean BAI is increasing. Exactly at that moment when the year 1976, with its very small BAI, is added to the calculation interval, the fluctuations start to increase dramatically, connected with a slight decrease in mean BAI. This pattern shows, that the magnitude of BAI fluctuation is not controlled by the mean level of BAI. Moreover, one can assume, that most likely external driving forces cause this special pattern. Because such growth patterns in beech stands are found currently in many cases, this contribution tries to formulate some scientific questions:

i.   Is increased sensitivity in ring width series a normal pattern due to ageing effects? Is it an indication of senescence?
ii. Is there a relationship between tree age and annual sensitivity?
iii. Is the climate warming over the last couple of decades the main cause of an increase in sensitivity in ring width series?
iv. Are beech trees able to overcome periods with increased sensitivity and return to normal growth patterns if climatic conditions become more suitable?

Material and methods

A comparative investigation of growth patterns in recent and medieval beech-chronologies was seemed appropriate to answer the above questions. In the case that senescence is the cause of increasing sensitivity with higher tree age, this relation should appear in the historical material as well. Similarly, periods of increased sensitivity should be detectable in the past as well if climatic stressors are the cause. In a sufficiently long chronology, alternating periods of increased and lowered sensitivity should appear. The mediaeval beech chronology from Greifswald situated at the north-eastern Baltic Sea coast, spans from 960 AD to 1296 AD. During these times the nearly virgin forests were unmanaged in the sense of regular thinning practice and scheduled stand treatment. Forests were only used sporadically to provide construction timber and fuel. For the latter use thin and young trees were preferred. At this time the forests were not affected by long-lasting air pollutants. From all series of this chronology only series exceeding 150 years were selected, in order to look for possible effects due to senescence. The sample material for tree ring measurements consists of split-planks, frequently containing the pith. In most cases, the last ring before felling was present. Therefore, the complete life spans of 53 beech trees were available for investigation. Within this chronology a replication of at least 20 per year exists between 1045 and 1259 AD.

The other side of this comparative investigation is formed by 12 recent beech chronologies sampled in northern Germany (from Schleswig-Holstein, Mecklenburg-Vorpommern up to Brandenburg) and northern Poland (Czajkowski 2006; Fig. 5) which consist of 320 sample trees all together.

Figure 5: Geographical positions of the investigated beech chronologies; fat point: Greifswald chronology

We used moving time spans of 21 years wherein mean sensitivity (Douglass 1936) and first order autocorrelation were calculated. The corresponding procedures are implemented into the computer program "LINDWORM" which enables a series by series search for changing patterns of sensitivity and AR(1). Among all possible combinations between these parameters some distinctive cases can appear:

(1) High autocorrelation and low sensitivity: High AR(1)-values indicate invariable growth trends together with a slight environmental effects This combination may be seen as attributes of stable growth conditions.

(2) High autocorrelation – high sensitivity: Compared to (1), this combination seems to be harmless as long as a high autocorrelation is accompanied by stable growth trends.

(3) Low autocorrelation – low sensitivity: Compared to (1), this combination also seems to be harmless as long as sensitivity is remaining at a low level.

(4) Low autocorrelation – high sensitivity: Contrary to (1), combinations in which a stable trend is lost and simultaneously growth rate fluctuations increase are an indication of stressed conditions.

The LINDWORM program determines these time spans where:

a) the most rapid change of the AR(1)-sensitivity relation (increasing sensitivity and decreasing AR(1)),

b) the lowest autocorrelation occurs,

c) the highest sensitivity occurs and when,

d) the strongest increase of sensitivity appears.

These four criteria (a to d) are used to calculate the relative amount of all included series which show the same pattern in each year of the chronology. The program was applied to the Greifswald-chronology and to the recent beeches. Within the program run the consecutive stepwise results are shown in movie-like animation. Here, only an example of the final investigation of a single series can be shown (Fig. 6).
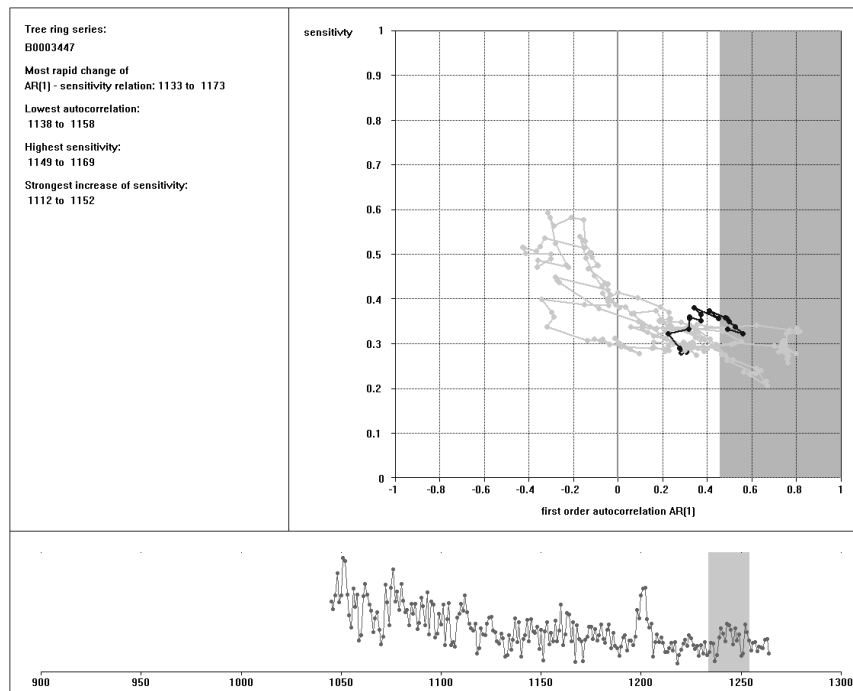
Figure 6: Example of a complete investigation of a single ring width series by the LINDWORM-program; upper graph: relation between AR(1) and sensitivity; temporal changes of this relation are shown as a grey trace; grey shaded area: range of significant correlation; lower graph: ring width time series; grey shaded area is the time span currently under investigation; results of this current time span are shown in the upper graph as black trace.

Results of the investigation of the Greifswald-chronology and of the recent beeches

The time range between 1045 and 1259 wherein replication is at least 20 per year, is used to valuate the temporal appearance of the criteria a to d as relative percentages of all included series. From these criteria only b and c presented here, because they are the most important ones (Fig. 7 and 8).
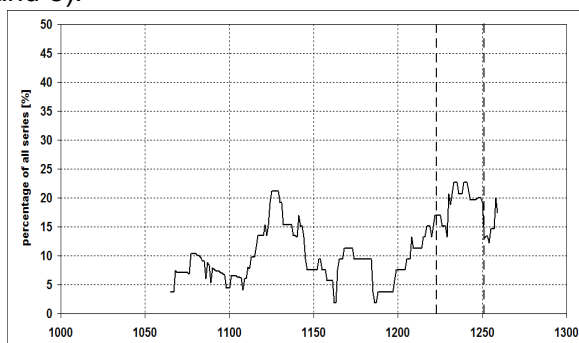
Figure 7: Greifswald chronology; criterion b): lowest autocorrelation
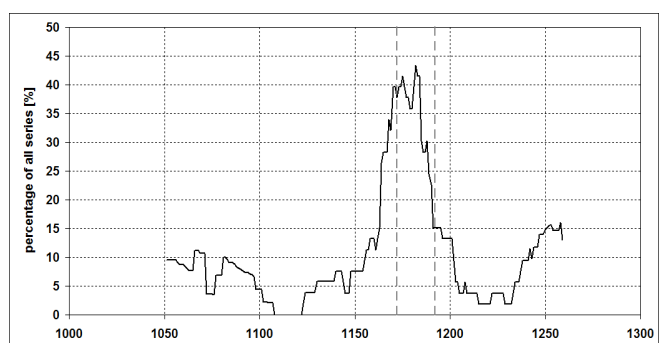
Figure 8: Greifswald chronology; criterion c): highest sensitivity

Concerning the collection of recent beeches from stands in northern Germany and northern Poland the range between the years 1895 and 2007 was used where at least 100 series are present (Fig. 9 and 10).
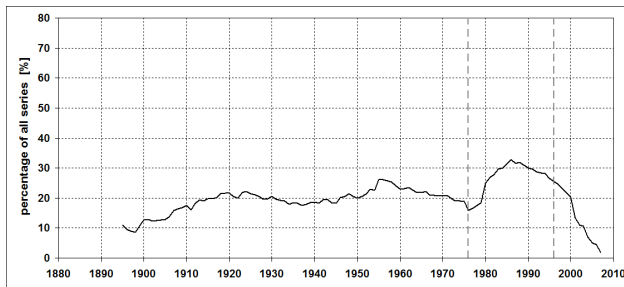
Figure 9: Recent beeches; criterion b): lowest autocorrelation
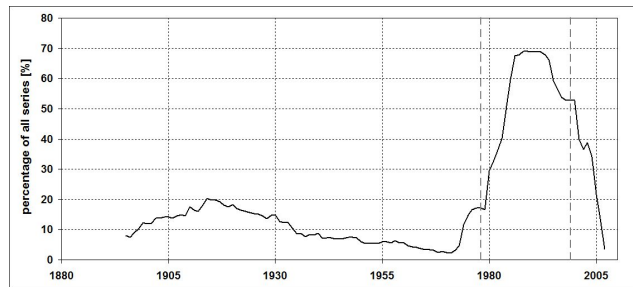
Figure 10: Recent beeches; criterion c): highest sensitivity

In order to ask to the question whether tree age affects sensitivity or not, the annual sensitivities of all series were compared with the corresponding tree ages (figures 11 and 12).
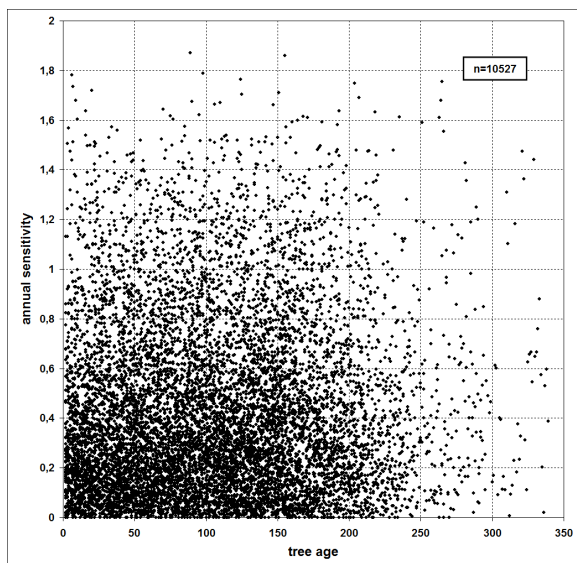
Figure 11: Greifswald chronology; age related annual sensitivities
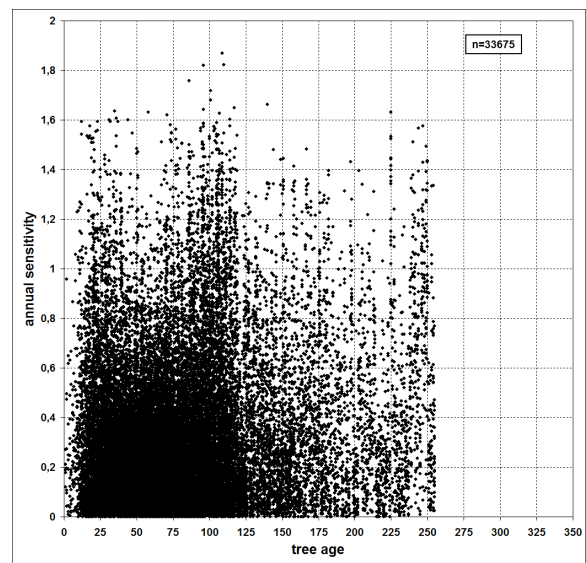
Figure 12: Recent beeches; age related annual sensitivities

Evaluation of results and discussion

Dramatic increases of sensitivity, accompanied by low autocorrelation, accumulate during specific periods. This pattern relates to both the medieval and the recent chronologies (Fig. 7 to 10). Periods with unfavourable changes in ring width series, i.e. the increase of sensitivity and the decrease of autocorrelation, do not appear at the end of the series. Therefore, such changes cannot be associated with increasing age or senescence. There is no apparent relationship between tree age and annual sensitivity (Fig. 11 and 12).This is contrary to the questions (i) and (ii), formulated in the motivation section. The advancing tree age cannot explain rapid changes and the return to normal growth patterns. Therefore, the hypothesis of senescence does not appear to be supported by these tests. It is supported by the historical as well as the recent chronology.

After periods of stressful conditions even old beeches are able to recover to normal growth patterns if growth conditions turn for the better. The simultaneous growth reactions between the series of the respective chronologies is likely driven by exogenous forces, because the changes are independent of tree age. So, question (iv) has to be confirmed. Otherwise, the repeatedly observed recent occurrence of increased sensitivity and lowered autocorrelation of beech chronologies (Fig. 1 to 4) can be seen as a momentary condition of these stands. It has to be

assumed, that these changes are driven currently by the climatic conditions which corresponds to the confirmation of question (iii). Their future development depends on the direction of further climatic changes.

The mean sensitivity of all 320 recent beech series is 0.32. This value is comparatively high, but consistent and can be explained by the widely spread sandy soils of northern Germany and Poland. The calculation of the mean sensitivity of the 53 Greifswald beeches leads to the surprising value of 0,41. If sensitivity is an expression of the strength of fluctuating growth conditions, the question of the corresponding climatic conditions for this chronology (960AD to 1296AD) arises. Instrumental climatic data of this time range which is part of the Medieval Warm Period are not available; however historical chronicles exist (Glaser 2001; Tab. 1).

Table 1: conspicuous climatic characteristics within the time range of the Greifswald chronology

time range/year	precipitation and temperature conditions
1003 to 1047	many cold, enduring and snowy winters
1021 to 1040	summer heat periods with extreme heat and drought
1043	extremely cold summer
1049 to 1053	wet and cool summers
1088 to 1107	predominantly mild, rainy winters, dry springs, hot and dry summers
1124 to 1126	cold and snowy winters
1127 to 1137	dry and hot summers
1141 to 1146	wet and cool summers
1155 to 1158	dry and hot summers
1159 to 1168	predominantly cold winters
1161 to 1310	longest time span with warm and dry summers, however: 1182 frost in June !

These chronicle data suggests that not only heat and drought during the Medieval Warm Period could have caused the outstanding high sensitivity, but time spans with opposing and extreme weather conditions led to these strong fluctuations of ring width. Compared to today's climate, the conditions a thousand years ago must have been much more changing and much more extreme (Glaser 2001). These huge climatic changes did not only occur during the Medieval Warm Period, but came along with the complete remigration of beech after the end of the Pleistocene. Common beech arrived in Germany during the late Atlanticum, the so-called Beech Warm Age, 4800 years ago. This period was followed by colder conditions during the Bronze Age (2200 – 1200BC), the climate optimum of the Roman Expansion (30BC – 250AD) and again by the coldness during the Barbarian Migration (250- 450AD). The Medieval Warm Period was followed by the so-called Little Ice Age (1400 -1800). Current warming began around 1850 (Akasofu 2010). It is really noteworthy that the common beech was able to cope with all these partially harsh and changing conditions.

Conclusions

Common beech exhibits a strong resilience towards unfavourable climatic impacts. The survival of this tree species may not be challenged by the on-going climatic changes. In the fields of forest management and silviculture there does not appear to be a reason to start overhasty actions at present, such as replacing indigenous by more drought tolerant species or provenances. Practical measures should only be taken based upon trusted findings, such as the conversion of non-indigenous spruce forests at low elevations sites. The level of knowledge on the ranges and limits of climatic stress tolerance for all important indigenous and foreign tree species has to be widened by systematic studies. Nevertheless, cultivation tests of foreign species should be conducted with new intensity.

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Preliminary results from ring width and latewood density measurements from the southeast Tibetan Plateau, China

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Introduction

The Tibetan plateau, with a mean elevation of more than 4.000 m asl. and an area of more than 2.000.000 km^2, acts as a heating surface during spring and summer and plays a key role in driving the different branches of the Asian summer monsoon circulation (Murakami 1987). During the last decades, temperature conditions on the Tibetan plateau (TP) have increased in a considerable higher magnitude than the northern hemispheric mean (Wang et al. 2001; Liang et al. 2009; Liu et al. 2010), especially during winter. This leads to higher snow precipitation during winter and a decrease of constantly frozen ground (Zhao et al. 2004). Model scenarios predict an intensification of the summer monsoon system under increasingly warmer climatic conditions (Liu et al. 2009), which is supported by positive precipitation trends in most regions of China (Zhao et al. 2004; Wu et al. 2006), with an increasing trend of heavy rainfall events (Liu et al. 2005). In order to derive realistic estimates on future water availability and/or flood risks, understanding the relationships between temperature and precipitation variations, glacier fluctuations and the variability of the Southwest- and East Asian Summer Monsoon as well as the Winter Monsoon is a crucial task.

Climate stations were not installed on the TP before 1950. In addition, as big differences in altitude occur in comparatively short distances, spatial interpolation of temperature and precipitation between distant data points may be questionable. Since different branches of the summer monsoon system react differently to atmospheric circulation patterns like ENSO, reconstructing and predicting changes in monsoonal patterns is a complex task that can only be assessed by a combination of approaches.

Previous studies on the TP revealed that maximum latewood density (MXD) is a good indicator of regional summer temperature (Bräuning & Mantwill 2004, Wang et al. 2010). High-frequency densitometry is a quick, non-destructive alternative to X-ray densitometry (Schinker et al. 2003). Tree-ring density variables, especially for maximum latewood density from cold moist sites, have great potential for reconstructing summer or growing season temperature (Duan et al. 2010).

Material and Methods

Site and species

In this paper, we present first densitometry measurements from tree-ring samples that were collected in 2004. The analyzed Sikkim Larch (*Larix griffithii*) trees originate from pioneer tree stands on lateral and terminal moraines of a glacier site near Bomi (29°50' N, 95°50' E, Fig. 1) at about 4000m asl. The upper tree line at north-facing slopes in Parlung Tsangpo valley reaches up to 4300m asl. From a total of 33 cores from 24 trees, the first four samples were analyzed in this preliminary study.
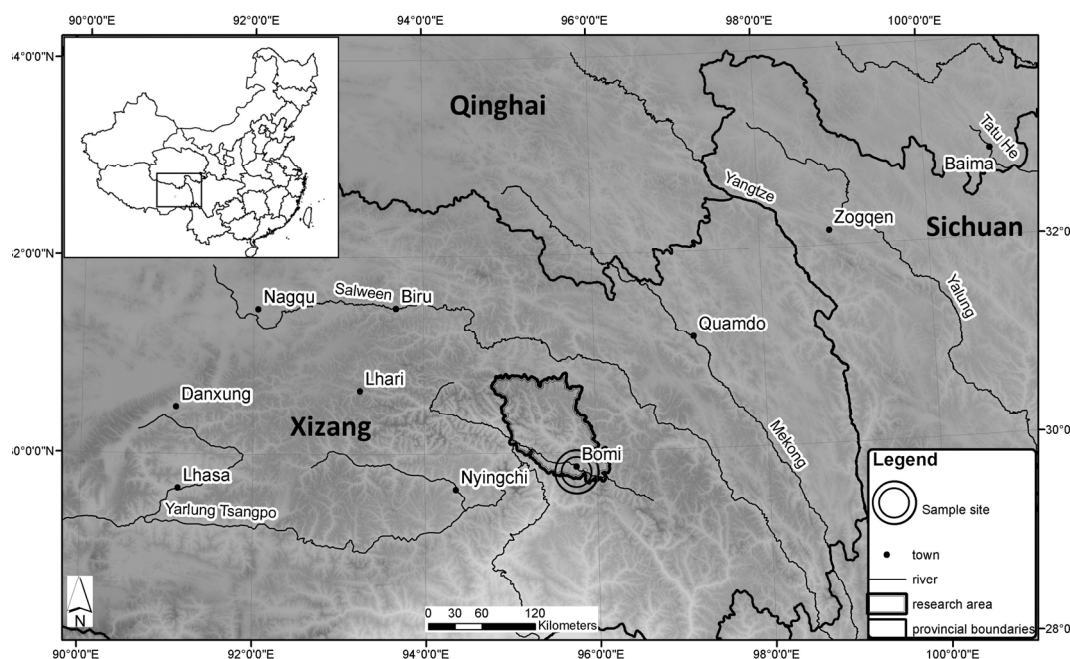
Figure 1: Map of the research area on the southeastern Tibetan Plateau showing the location of the study site.

Climate

The regional climate is strongly influenced by the southwest Asian summer monsoon (SASM), with an early onset of pre-monsoonal rainfall and a second precipitation maximum during the autumn rain period, as it is characteristic for parts of the Longitudinal Range-Gorge Region (He et al. 2007). The climate station Bomi which is close to the study site is running since 1961 and shows an average precipitation of 836mm per year and a mean temperature of 8.3°C.

Measurements and data treatment

Tree-ring samples were processed using standard dendrochronological practices (Stokes & Smiley 1968). Cores were first dried and cut using razor blades, then chalked for better contrast. Consecutively the samples were measured using a LINTAB II measuring system with a resolution of 0.01 mm. All series were checked visually and statistically. For densitometric analyses, these samples were glued onto carriers and further treated using the Lignostation densitometry system (Rinntech, Germany; Rinn 2006, Schinker et al. 2003). Relative density variations were measured along smoothed wood surfaces using a high-frequency dielectric scanner with a spatial resolution of 10 µm. For each ring, three parallel paths were measured to minimize biases from e.g. non-visible resin ducts. Although earlywood width, latewood width, minimum and maximum density were also determined for each year, only RW and MXD data were used in this preliminary study as they are expected to be the best tree-ring parameters for the reconstruction of past temperatures (Bräuning & Mantwill 2004).

For correct dating of the density series, ring width curves measured with Lignostation were crossdated with the LINTAB curves using the program TSAP (Rinn 2003). In order to remove biological trends associated with tree-age (Fritts 1976) while preserving variations that are likely related to climate, the tree ring series were standardized to dimensionless indices using the program ARSTAN (Cook 1985). After stabilizing the variance using a data-adaptive power transformation, ring-width measurements were detrended with a cubic smoothing spline with a 50% frequency response cut-off equal to 2/3 of the series length. In the case of MXD, negative or

zero slope linear regression functions, whose values were substracted from the raw data, were used to remove the age trend. This process removes or reduces the influence of disturbance and changes in tree growth with age, while preserving inter-annual to multi-decadal scale variability in the tree-ring series (Fan et al. 2009). Though this method may induce artificial cooling or warming on a low-frequency scale, it has only a variance-stabilizing effect on the high-frequency signals, leading to the consequence that the absolute values during the youth of the trees, when they exhibit strong growth rates, are not overrated in comparison to a later period of only minor increment.

Determination of pointer intervals

In order to indentify forcings common to all series, pointer intervals (Schweingruber et al. 1990) were extracted by substracting index value x -1 from the index value for year x. To account for the low number of samples, the consistency of growth tendency was set to 100%. Pointer values were classified using the difference in standard deviations over all four series; in case of equality the value from the preliminary chronology tipped the scale. Values lower than one standard deviation (normally grade 1) were discarded, index values between single and doubled standard deviation were marked grade 2 and values exceeding two standard deviation as grade 3 for the respective parameter (Bräuning 2002).

Results

The individual series length was 172, 195, 206 and 221 years. Two cores of each tree were crossdated and combined to form one series respectively, regarding both RW and MXD.

We found significant similarities between ring width and maximum latewood density. Gleichlaeufigkeit values between the two parameters for samples BoD8_19, -20, -21 and -24 were between 61-67% (p<0,001). Of special notice are the common maxima and minima (Figs. 2 and 3).
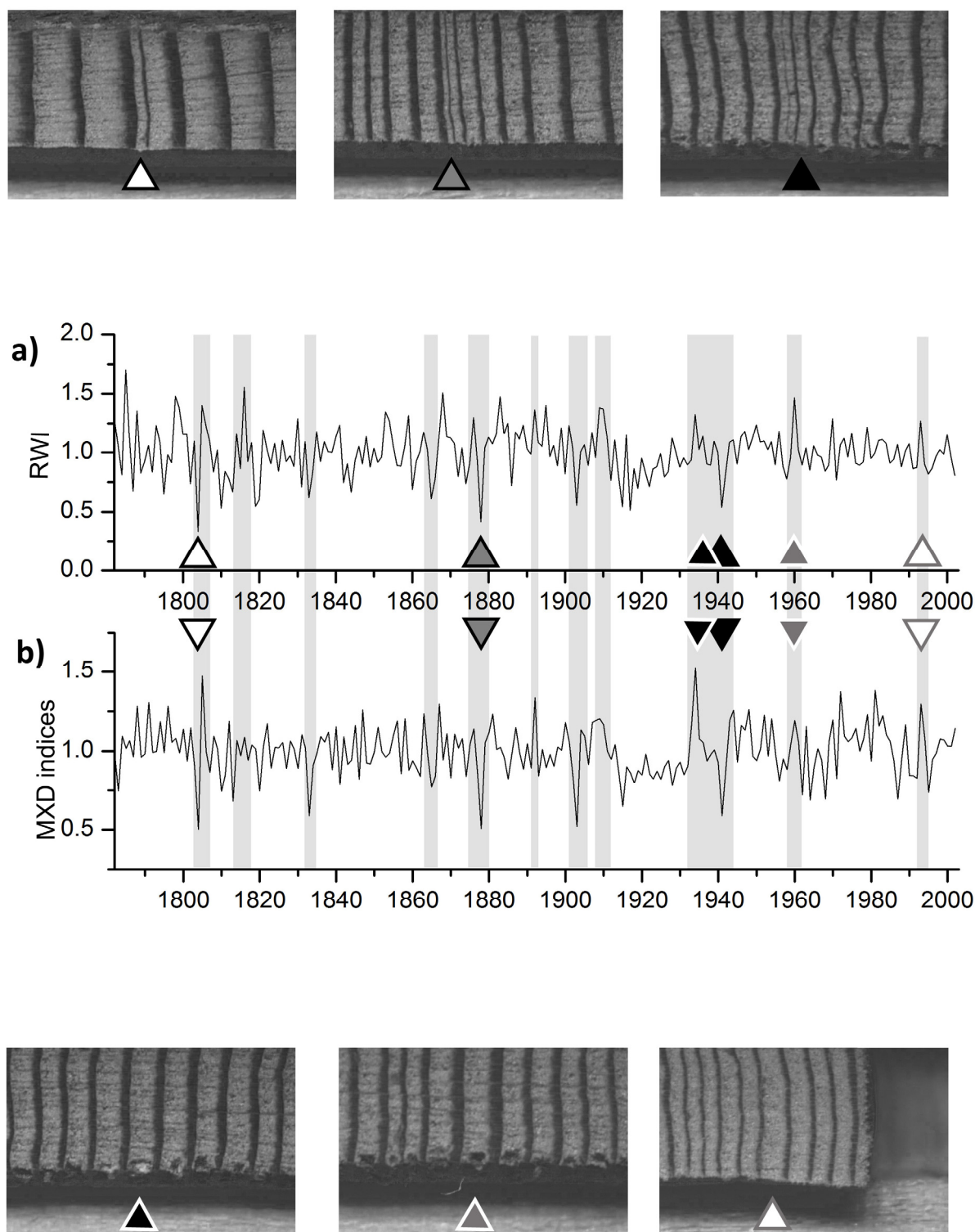
Figure 2: Ring width (a) and Maximum latewood density (MXD)indices (b) of sample BoD8_19 between 1789 and 2003; periods with significantly high or low values in both parameters are marked in grey. Microscopic photos of years with very low growth and MXD(upper line) show rings of 1803, 1878 and 1903; High growth and density appear in 1935, 1960, 1998 (white arrows).

Pointer intervals

Negative grade 3 pointer intervals for MXD were found in 1878, 1903 and 1915, for ring width in 1878, 1903 and 1917, while no positive grade 3 intervals could be found. So an overall tendency observed for the analyzed series is that negative pointer intervals deviate from the mean to a greater degree than positive ones.
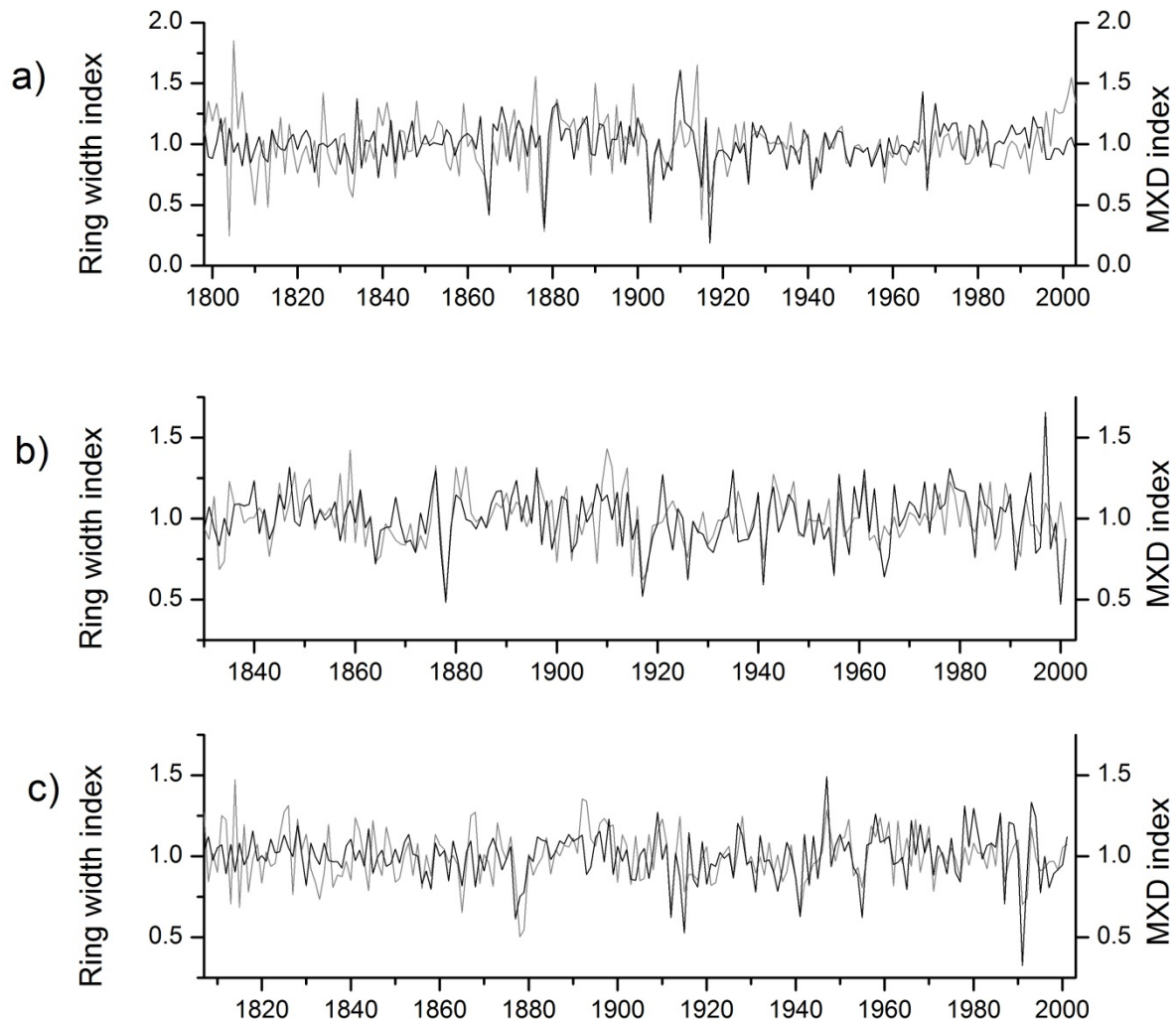
Figure 3: ring width (grey) and maximum latewood density (black) of samples a) BoD8_20, b) BoD8_21 and c) BoD8_24.

As instrumental data from Bomi climate station is only available since 1961, both parameters of the individual series were correlated with the 1961-2003 instrumental period for temperature and precipitation.

Two years are picked out as examples for a demonstration how different climatic constellations are reflected in growth patterns at this high-elevation site.

1987 is a negative grade 2 pointer interval in terms of MXD whereas ring width is well within half a standard deviation. As ring width is known to be correlated with previous winter temperature (Yang et al. 2010; Gou et al. 2007) and MXD with late summer temperature (Duan et al. 2010, Wang et al. 2010), this would suggest a cool summer after a mild winter. The data from the weather station at Bomi expresses general agreement with this hypothesis (Fig. 4a); additionally the strong correlation between MXD and late summer temperature is clearly visible.

In contrast, 1962 is a negative grade 2 pointer interval for ring width, MXD also has a slightly negative trend but is still within one standard deviation. Consecutively, this combination would point towards a harsh winter, followed by a mild, a little cool summer. If the strength of the central Asian cold continental pressure system is taken into consideration as an influence on both winter temperatures and thus the onset and strength of the Indian summer monsoon, this would consequently require a relatively weak monsoon system, thus a dry year. Comparison with climate data confirms this interpretation of these growth reactions (Fig. 4b)
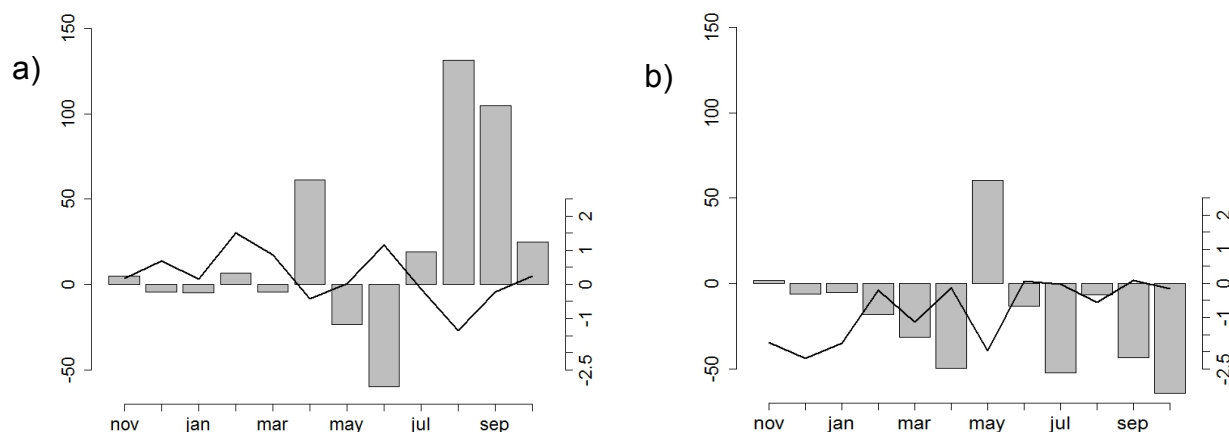
Figure 4: Monthly values for 1987 (a) and 1962 (b). Shown are deviations from the monthly longterm average in precipitation in mm (left y-axis) and in temperature in °C (right y-axis).

Discussion and outlook

We found significant similarities between tree-ring width and maximum latewood density in samples of high-elevation *Larix griffithii* growing at glacier-near sites. After removal of age trends, years with very low ring width are most likely to have an even more extraordinary low density. Strong relationships between MXD and summer temperatures on the TP have been found repeatedly (Bräuning 2006, Wang et al. 2010, Bräuning & Mantwill 2004). For ring width, high correlations with winter and spring temperatures on the one hand and with annual precipitation on the other hand were reported (Yang et al. 2009, Yang et al. 2010, Liu 2011). Thus, combining both parameters can reveal a surplus of information about climatic history than each variable itself. The two combinations presented in this preliminary study represent two weather conditions, an enhanced activity of the Indian summer monsoon in 1987 and a weak occurrence in 1962. Although this seems to be recorded well by high-altitudinal tree stands, further analysis of more material is necessary to accept or reject these preliminary ideas. Provided that these situations have been occurring in the past repeatedly, high-frequency analyses are a promising way to reconstruct frequency distributions.

Ring width and MXD chronologies for the study site will be completed and further statistical treatment will be carried out. The relationships between ring width, maximum latewood density and climate seem to be apparent; though, they require additional sample depth and statistical analyses to reconstruct former climate variations at this site.

Acknowledgements

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Climate response of radial growth of silver fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* (L.) Karst.) in the Black Forest, Germany

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Introduction

In Baden-Württemberg, southwestern Germany, the economically important silver fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* (L.) Karst.) occupy 8% and 36% of the forestland (BMELV 2008), respectively. More than 60% of silver fir forest in Germany is found in Baden-Württemberg (BMELV 2008).

For the 21st century, temperature in Central Europe is predicted to increase up to 3-4°C, whereas the seasonality of precipitation will change and the amount of precipitation will decrease (Christensen et al. 2007). Heatwaves, such as experienced in 2003, are predicted to become more frequent (Meehl & Tebaldi 2004, Schär et al. 2004) and may reduce growth enormously (Ciais et al. 2005). Fir and spruce are known to be sensitive to summer drought (Becker et al. 1989, Desplanque et al. 1998, Rolland 1993, Spiecker 1986, 1991) and their susceptibility to changing climate conditions is likely to be greater at sites which are suboptimal, i.e. at south-exposed sites and low altitudes. In order to predict how trees might react to changing growing conditions at such sites, retrospective tree-ring based studies can be used. Tree rings provide insight into past environmental conditions, as intra-annual as well as year-to-year variations in growth can often be attributed to changes in climate. Separate analysis of earlywood and latewood may provide additional information about the periods and climatic factors influencing annual radial growth (Lebourgeois et al. 2000, Lingg 1986) as they are formed at different times in the year.

Long-term relationships between growth and climate may be established using correlation analysis. However, this kind of analysis shows the average linear relationship between growth and climate variables (Guiot 1991), but does not provide information on less frequent and time-dependent growth limiting factors (Lebourgeois et al. 2010). The analysis of extraordinary growth reactions, so-called pointer years (Schweingruber et al. 1990), in relation to climate has proven to provide quantitative information on growth reactions of trees to extreme climatic events (e.g. Desplanque et al. 1999).

The aim of this study was to investigate both climate-growth relationships of earlywood, latewood and total annual radial increment, as well as the occurrence of pointer years in silver fir and Norway spruce in the Black Forest in southwestern Germany. We analyzed spruce at high elevation and fir at high and low elevation. All sites were on south- to southwest-exposed slopes.

Material and Methods

Study sites

Study sites were selected in a two-step procedure. First, we made a pre-selection from digital forest classification (Regierungspräsidium 2009) and soil data (FVA 2009) in ArcGis® Desktop10 (criteria: main *tree species* (fir or spruce) and *age class* (100-120 years)). Second, we made a final selection of seven stands based on *altitude* (low sites at 400-450m and high sites at 970-1140 m), *exposition* (south- to southwest) and comparable *forest structure*. In addition, a high-altitude spruce stand from a former research project was included (Table 1).

Table 1: Description and characteristics of study sites. Sites where both tree species were collected are indicated by a number with suffix (a,b). AWC available water capacity: 1 = very low (<50 mm), 2 = low (50-90 mm), 3 = medium (90-140 mm).

Site	Lat. (°N)	Long. (°E)	Altitude (m a.s.l)	No. of trees	Time span (all trees)	Age (years)	Aspect	AWC
Norway spruce								
TODT	47.86	7.92	1140	5	1902-2006	118.6 (105-137)	SWW	2, 3
SIRN	47.80	7.77	1040	5	1921-2010	94.6 (90-100)	SW	2, 3
KUHLS	47.78	7.79	970	5	1903-2010	112.4 (108-117)	SWW	1, 2
Silver fir								
KOHL	47.79	7.77	1050	4	1921-2010	107.3 (90-129)	SW	2, 3
FISC	47.78	7.77	985	5	1917-2010	96.6 (94-98)	SWW	2, 3
KUHLF	47.78	7.79	970	4	1913-2010	100.8 (98-104)	SWW	1, 2
SULZ	47.84	7.72	450	4	1927-2009	86.8 (83-92)	SSW	2. 3
WALD	48.11	8.01	430	5	1910-2010	109.8 (101-123)	SW	2, 3
MUGG	47.83	7.69	400	5	1924-2010	103.2 (87-115)	SW	2, 3

Monthly average air temperatures and precipitation sums at the different sites vary with altitude (Fig. 1). Cambisol is the predominant soil type and the available water capacity (AWC) ranges from very low (<50 mm) to medium (90-140 mm) at our sites (Regierungspräsidium 2011).
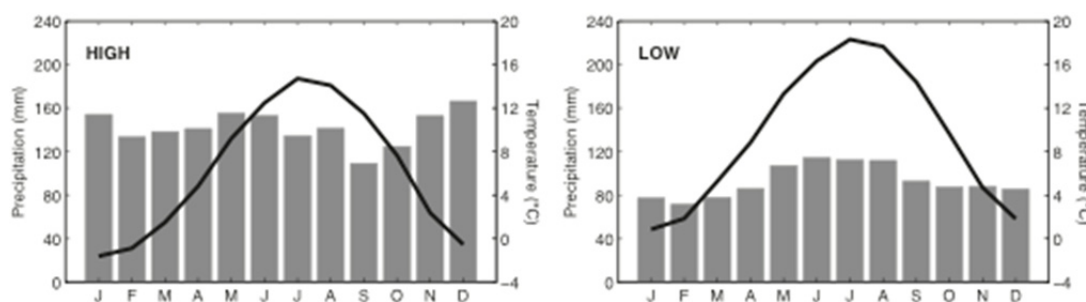
Figure 1: Climate diagrams with mean monthly precipitation sums (mm) and temperatures ( ) over the period 1961-1990 at the high- and low-altitude sites.

Tree-ring data

Per site, we collected stem discs at breast height of five dominant or co-dominant spruce or fir trees. Discs were air-dried and sanded with progressively finer grits of sandpaper to highlight annual rings. Annual radial increment was measured in eight pre-defined directions using semi-automatic image analysis software (developed at the Institute for Forest Growth). Individual tree-ring series were calculated using the quadratic means of the eight radii, and cross-dated visually and statistically (*Gleichläufigkeit*). Cubic smoothing splines with 50% frequency cut-off at 30 years were fitted to each chronology to retain high-frequency variations (Cook & Peters 1981), using MATLAB®'s (V7.9.0, R2009b) function *csaps* (V3.3.7) in combination with the spline smoothing parameter function *splinep* (presented courtesy of J.L. Dupouey). Observed values were divided by predicted values to produce dimensionless indices. The indices were then averaged to site chronologies using an arithmetic mean. In addition, the amount of early- and latewood was measured. We separated earlywood and latewood on the 50% grey value level between the maximum and minimum grey value of each annual ring. Earlywood and latewood series were detrended similar to the total radial increment series.

For each tree we calculated the inter-series correlation (IC), mean sensitivity (MS) and first-order autocorrelation (AC) over the common overlap period 1930-2006. Values were averaged per stand. The IC is a measure for the strength of the common signal in the chronologies, MS is a measure of year-to-year variability and AC assesses the influence of the previous year conditions upon current years' growth (Fritts 1976). Furthermore, the Expressed Population Signal (EPS) was calculated using the *wigley1* function (presented courtesy of D. Meko). The EPS value measures

the degree to which a particular chronology drawn from a finite number of trees portrays the theoretical perfect chronology based on an infinite number of trees (Wigley et al. 1984). All computations were carried out using MATLAB® (V7.9.0, R2009b).

Statistical analysis and climate-growth relationships

Principal component analysis (PCA) was performed to investigate differences and similarities in growth variations of the site chronologies and to detect altitude- and species-specific growth patterns. PCA is a data reduction method summarizing a data matrix (in this case: of chronologies) in a set of components, where the first component explains most of the variance in the dataset.

Site-specific monthly air temperature and precipitation data were extracted from a gridded climate surface (1×1 km) for the period 1900-2009, derived from the Web-based Weather Request and Distribution System (WebWerdis) of the German Weather Service (DWD). To determine the climate factors mainly responsible for the growth variations found, bootstrapped correlation coefficients were calculated for the period 1930-2006 using the software package DENDROCLIM2002 (Biondi & Waikul 2004). Monthly climate data from April of the previous year to September of the current year, and seasonal temperature means and precipitation sums of April-August, May-August and June-August of the current year were considered, hereinafter referred to as season *I*, *II* and *III*. In order to analyze longer lasting influences of climate on tree growth, chronologies and climate data from season *I* have been smoothed by a 5-year moving average.

Pointer year analysis

For the analysis of negative pointer years we calculated so-called Cropper values by dividing the raw measurements of single tree-ring series by their 5-year moving average (Cropper 1979). Cropper values (C) were normalized to a mean of zero and a standard deviation of one (Neuwirth et al. 2007) over the common period 1930-2006. Following the thresholds proposed by Neuwirth et al. (2007) we identified a year as negative pointer year when more than 60 % of the trees in a group exceeded the threshold of $C < -1$. We did not consider years with positive pointer years, as strong positive growth reactions are often caused by a combination of several favorable factors, e.g. silvicultural practices or growth recovery after depression, rather than a single climate anomaly (Rolland et al. 2000).

Results

Tree-ring characteristics

Mean annual radial increment ranged from 1.69 to 3.59 mm (Table 2). Earlywood represented 60-70% and 70-75% of the annual ring in fir and spruce, respectively. For the period 1930-2006, the IC of the sites varied from 0.644 to 0.836 for total radial increment. A high IC was also found between all high-altitude fir (0.71), low-altitude fir (0.65) and high-altitude spruce trees (0.75), indicating a common signal in the tree growth response to climate within sites and groups. MS values were higher for latewood than for earlywood and total radial increment for all sites, and were higher in low-altitude fir sites compared to the high-altitude sites. This suggests a greater climate sensitivity of latewood and trees at low-altitude sites. AC was highest for radial increment at all sites. For all sites the EPS value exceeded the critical value of 0.85 proposed by Wigley et al. (1984), indicating strong common signals.

Table 2: Chronology statistics of increment series. Means were calculated for the period 1930-2006. RI radial increment (mm/year) with standard deviation (SD), IC inter-series correlation, MS mean sensitivity, AC first-order autocorrelation.

Site	Total ring				Earlywood				Latewood			
	RI	IC	MS	AC	RI	IC	MS	AC	RI	IC	MS	AC
Norway spruce												
TODT	1.69 (0.59)	0.82	0.16	0.57	1.13 (0.48)	0.80	0.20	0.50	0.56 (0.18)	0.68	0.19	0.37
SIRN	2.65 (0.71)	0.84	0.15	0.53	1.98 (0.59)	0.84	0.17	0.48	0.68 (0.17)	0.77	0.22	0.18
KUHLS	2.19 (0.69)	0.71	0.15	0.38	1.56 (0.54)	0.70	0.18	0.33	0.65 (0.24)	0.61	0.25	0.14
Silver fir												
KOHL	3.05 (1.24)	0.71	0.19	0.43	2.11 (0.97)	0.66	0.23	0.34	0.98 (0.42)	0.59	0.27	0.22
FISC	2.75 (1.07)	0.75	0.16	0.44	1.65 (0.70)	0.67	0.19	0.27	1.13 (0.55)	0.69	0.24	0.20
KUHLF	3.10 (0.90)	0.70	0.15	0.29	1.90 (0.70)	0.57	0.20	0.15	1.30 (0.50)	0.57	0.22	0.13
SULZ	3.59 (1.58)	0.64	0.23	0.30	2.32 (1.15)	0.62	0.28	0.29	1.31 (0.57)	0.58	0.28	0.12
WALD	3.16 (1.44)	0.74	0.27	0.07	1.89 (1.04)	0.63	0.32	0.09	1.39 (0.66)	0.64	0.36	-0.12
MUGG	2.86 (1.47)	0.74	0.29	0.27	1.69 (0.95)	0.71	0.32	0.21	1.21 (0.68)	0.72	0.37	0.21

Growth variability

PCA's were performed on high-altitude fir and spruce chronologies (HFS), and high- and low-altitude fir chronologies (HLF), to reveal species- and altitude-specific growth differences, respectively. The first and second principal component (PC1 and PC2) of the HFS-PCA account for 82.3% of the variance that is present in the six chronologies (Fig. 2a). PC1 explains 63.1% of the variance, indicating a strong common signal. PC2 accounts for 19.2% of the variance, indicating species-specific growth patterns.
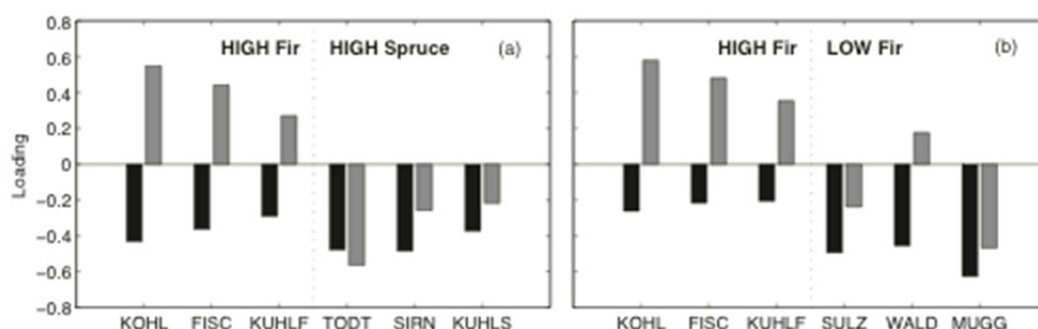
Figure 2: Loadings of the principal components PC1 (black) and PC2 (grey) for (a) high-altitude fir and spruce sites (PC1: 63.1%; PC2: 19.2%) and (b) high- and low-altitude fir sites (PC1: 53.8%; PC2: 26.4%).

The first two components of the HLF-PCA explain 53.8% and 26.4%, respectively. The loadings of PC1 are negative for all chronologies. The common variance suggests that a large-scale factor, i.e. climate, affected all sites in a similar way. PC2 describes the major differences between the chronologies and separates two low-altitude fir stands from the other stands (Fig. 2b).
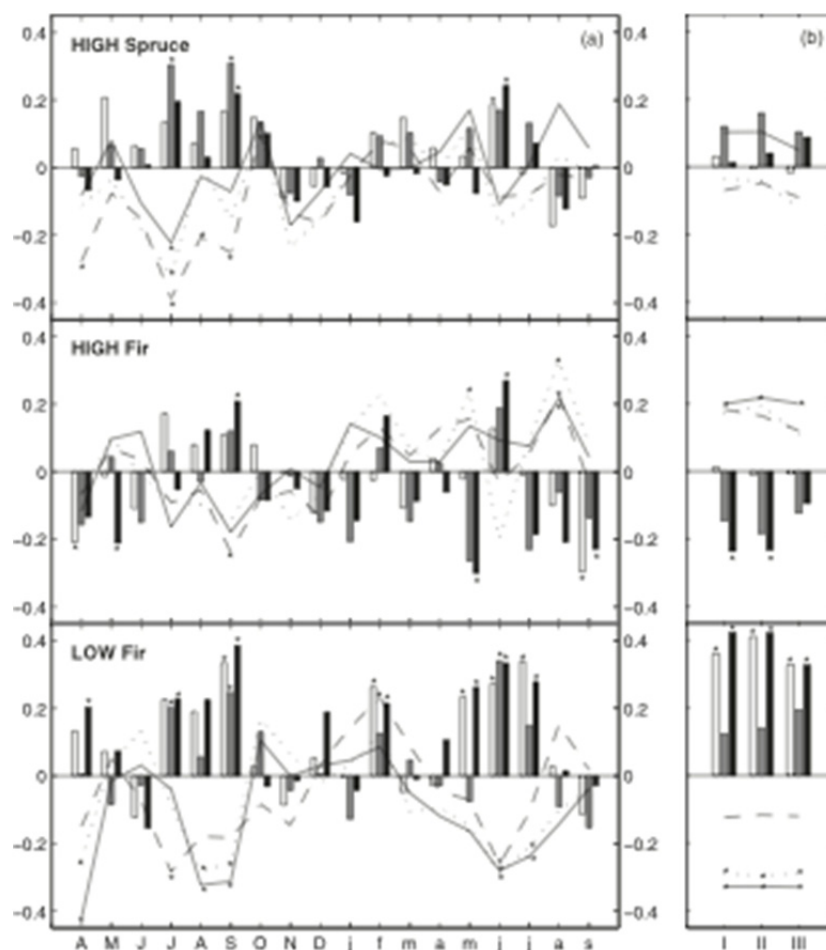
*Figure 3: Bootstrapped correlation coefficients between the site chronologies of high-altitude spruce, high-altitude fir and low-altitude fir sites and (a) monthly and (b) seasonal temperature and precipitation data. Climate data from previous April till September of the current year has been considered. Seasonal means are averaged over: I = April-August, II = May-August, III = June-August. Precipitation (bars; white, grey, black) and temperature (lines; —, ---, :) for the three plots per group (TODT, SIRN, KUHLS; KOHL, FISC, KUHLF; SULZ, WALD, MUGG), *significant correlations (P < 0.05).*

Climate-growth relationships

The climate response of individual site chronologies was assessed by bootstrapped correlation analysis (Fig. 3). For low-altitude fir, positive correlations with summer precipitation and negative correlations with summer temperature in the previous and current year indicate summer water availability as the main factor controlling growth of these trees. On the other hand, growth of high-altitude fir is positively related with temperature in May and August, whereas precipitation during the growing season is generally found to have a negative influence. Therefore, these high-altitude fir trees seem to be temperature-limited rather than precipitation-limited. This opposite relation between growth of low- and high-altitude fir and temperature and precipitation is confirmed by the correlation coefficients of the seasonal means (Fig. 3b). Further, the seasonal means indicate that site WALD is less drought-sensitive than the other low-altitude fir sites, possibly explaining the different growth signal revealed by the opposite loading of the second principal component (Fig. 2). Both high precipitation amounts and high temperature in February favor growth of low-altitude fir. For high-altitude fir a non-significant positive correlation with temperature in January and February is found.

Low temperatures and high precipitation amounts in the previous year favor growth of high-altitude spruce, and also precipitation in current June is found to have a positive influence on growth of these trees. Therefore, high-altitude spruce seems to be water-limited, but tends to show a negative growth reaction earliest in the next year.

The bootstrapped correlation analysis with early- and latewood chronologies provided additional information about the effect of climate on tree growth (Fig. 4). For earlywood of low-altitude fir and high-altitude spruce significant correlations are found with temperature (negative) and precipitation (positive) in the previous summer, indicating that warm and dry conditions in the year prior to growth negatively affect the formation of earlywood.

Current year conditions have a major influence on the production of latewood. For low-altitude fir, high temperatures and low precipitation amounts in June, July and August reduced latewood formation. The findings for high-altitude fir were opposite to those of low-altitude fir, as warm and dry summer conditions were found to increase the amount of latewood in high-altitude fir. For high-altitude spruce, temperature in July and August negatively affects latewood production.
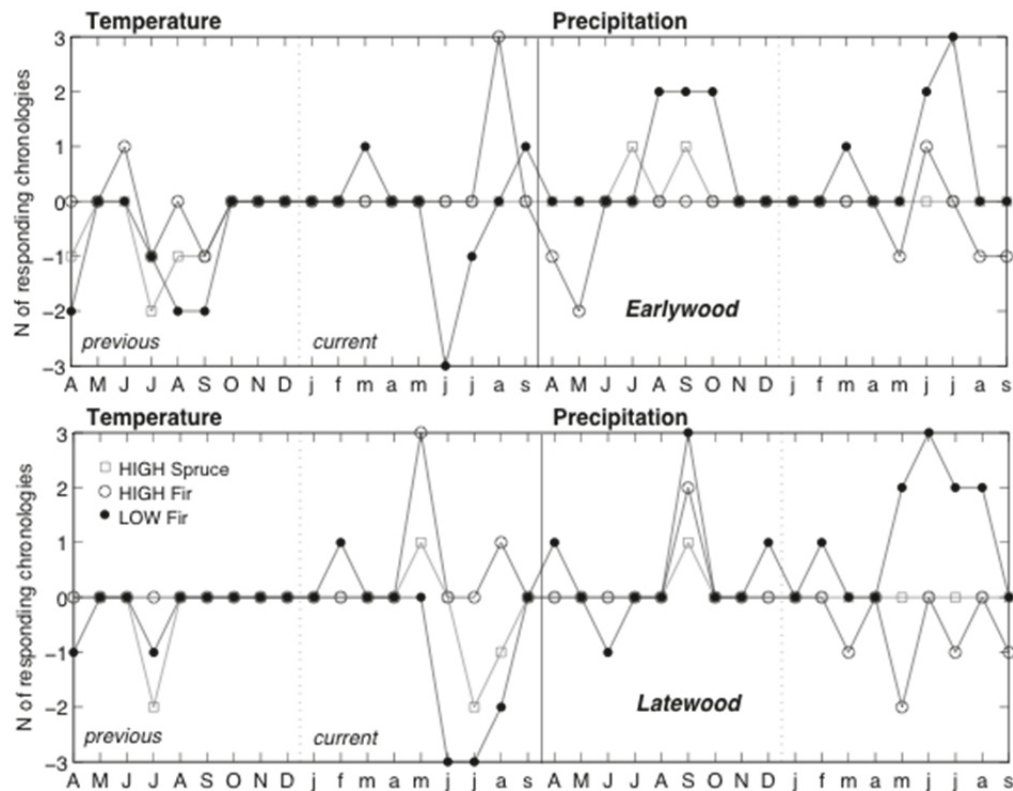
Figure 4: Summarized growth responses for earlywood and latewood to monthly temperature and precipitation for high-altitude spruce, high- altitude fir and low-altitude fir sites. The number (N) of chronologies with a significant (P < 0.05) negative or positive response from April of the previous till September of the current year is shown.

Long-term variations in growth in relation to climate

The correlations between long-term fluctuations in temperature, precipitation and tree growth are in line with the results of the bootstrapped correlation analysis. The long-term fluctuations of seasonal precipitation and growth of high-altitude spruce and low-altitude fir are positively correlated (Fig. 5). This indicates water-limiting growing conditions. Further, low-altitude fir is negatively correlated with temperature, whereas high-altitude fir shows a strong positive correlation. For high-altitude spruce there seems to be a negative one-year lagged temperature effect (r = -0.28, p = 0.01), meaning that high temperatures negatively affect growth during the next vegetation period.
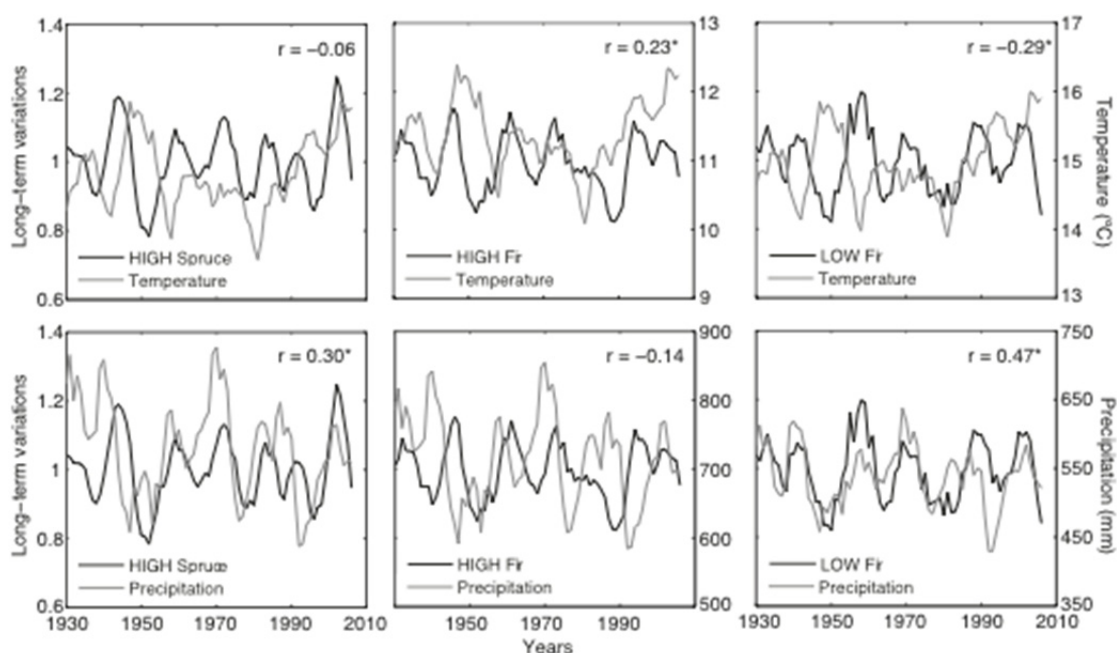
Figure 5: Standardized altitudinal- and species-specific chronologies and average temperature and precipitation from April to August (season I). Chronologies and climate data were smoothed by a 5-year moving average. The Pearson correlation coefficients are indicated in the upper right corner of each graph (*significant correlation, P < 0.05).

Pointer years

The number of negative pointer years for total radial increment ranges from 4 (high-altitude spruce) to 7 (high-altitude fir) for the period 1930-2006 (Fig. 6). In 2006, all groups showed a growth reduction, possibly because of high temperatures and low precipitation amounts in June and July of that year. Reduced temperatures in January and February and persisting effects of preceding dry years, together with high fructification (Meining & von Wilpert 2006), may have strengthened the growth depression.

In other years clear differences in negative growth reactions exist between altitude and species. Specific pointer years for high-altitude fir in this study include 1940, 1956 and 1987. These growth reductions are attributed to exceptional winter frosts. In January 1940 average temperatures in the high-altitude fir stands reached -6.5 °C, in February 1956 it was -11.6 °C and in January 1987 -6.8 °C (mean temperature 1961-1990: -1.6 °C). In 1986, temperatures in February were also lower than normal (-7.8 °C), which could have intensified the negative growth reaction in 1987. Further, high precipitation amounts during the growing season of 1940, 1956 and 1987 may have negatively affected growth of high-altitude fir.

Years in which mainly low-altitude fir showed a strong growth reduction are 1934, 1950 and 1962. These years are characterized by dry conditions (1934, 1962) or follow a year with below-average precipitation (1949).

In 1976, both high- and low-altitude fir showed a growth depression, which is attributed to low precipitation in spring and early summer. However, dry periods during 1971-1975 may have reduced the vitality of fir, enhancing the effect of the 1976 drought.

High-altitude spruce showed no specific pointer years. However, it had growth depressions in common with high-altitude fir (1948, 1995) and low-altitude fir (2003). The growth depression in 1948 might be an effect of the drought in 1947, but may be intensified by below-average temperatures in June and July in combination with above-average precipitation in July. Also 1995 is characterized by above-average precipitation amounts. In 2003, especially the growth of high-altitude spruce (class according to Neuwirth et al. (2007): "extreme") and low-altitude fir ("weak" and "strong") was reduced, because of a combination of extreme low precipitation starting in February and high temperatures in June, July and August. Less than 50% of the high-altitude fir ("weak" and "strong") trees reacted negatively. This could be related to a positive effect of higher temperatures on growth of these trees in combination with normal precipitation in May and preceding years that were sufficiently wet.
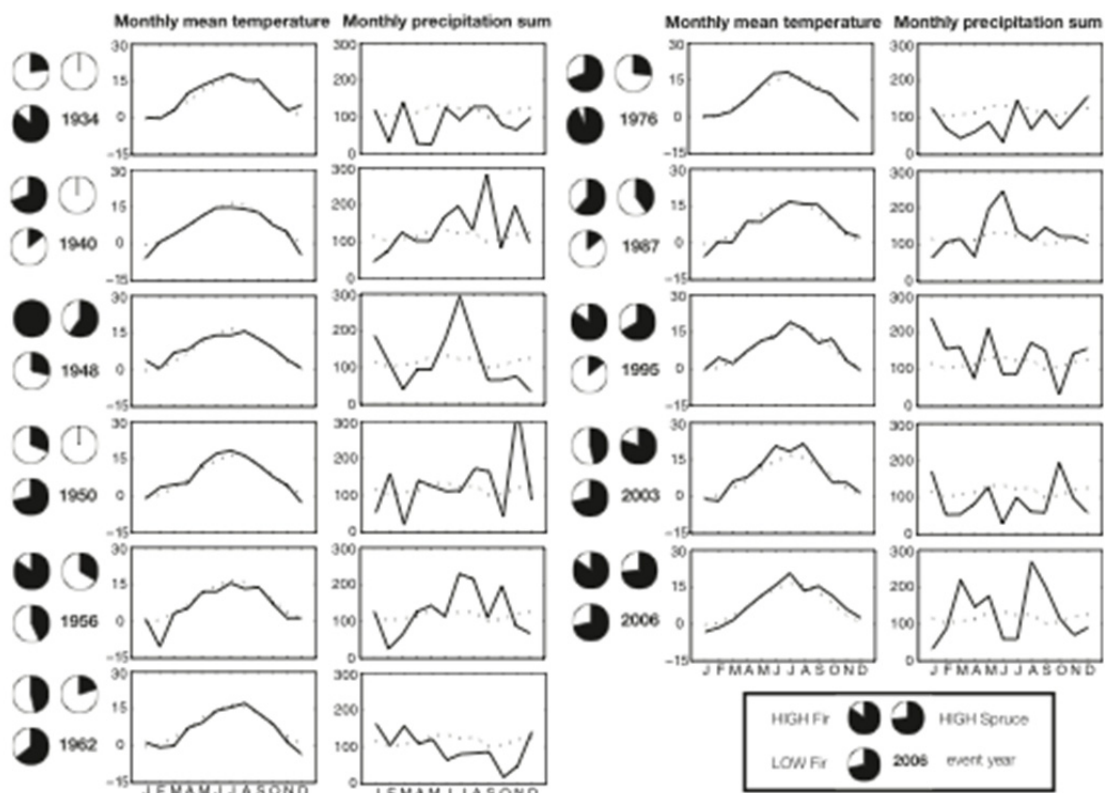
Figure 6: Overview of pointer years in high-altitude fir (n = 13), high-altitude spruce (n = 15) and low-altitude fir trees (n = 14) and climate diagrams. The black segments in pie charts shows the percentage of trees having a pointer year. Solid lines indicate mean monthly air temperature (left) and monthly precipitation sums (right), whereas dotted lines display average climate conditions over the Climate Normal Period (1961-1990). Presented climate data are means of high- and low-altitude sites.

Discussion

Our aim was to investigate growth variations, climate-growth relationships and the occurrence of pointer years in silver fir and Norway spruce in the Black Forest in southwestern Germany.

The first principal component (PC1) of the PCA's revealed a strong common signal in the site chronologies, which is attributed to the factor limiting growth at all sites, being climate. PC2 showed differences between high-altitude fir and spruce, and high- and low-altitude fir, presuming species- and altitude-specific differences, respectively.

The bootstrapped correlation analysis indicated clear differences in climate sensitivity of the three groups. The difference between high- and low-altitude firs is best described by the correlations with seasonal means (Fig. 3b). Fir at high elevation is negatively related to precipitation and shows a positive response to temperature during the growing season, whereas fir at low elevation has an opposing relationship with both climate factors, suggesting temperature limitation and drought sensitivity, respectively. The importance of water availability for tree growth at low altitudes and the positive effect of temperature at high altitudes are known (e.g. Mäkinen et al. 2002, Neuwirth et al. 2004, Rolland et al. 2000, Wilson & Hopfmüller 2001). However, high-altitude spruce sites did not show a positive correlation with current-year temperature. Growth variability of these trees is determined by climate conditions in the year prior to growth, which is consistent with earlier findings (Bouriaud & Popa 2009, Lebourgeois et al. 2010). Favorable conditions in previous summer and fall increase the carbohydrate storage favoring growth in the following year (Fritts 1976, Kozlowski & Pallardy 1997).

Separate analysis of earlywood and latewood indices highlighted distinct seasonal patterns between species and ring components (Fig. 4). Especially in low-altitude fir and high-altitude spruce, earlywood was related to climate conditions in previous-year late summer. Further, latewood production in low-altitude fir mainly depended on high precipitation amounts and low temperatures during summer, whereas latewood in high-altitude fir is favored by opposite conditions.

Long-term growth variations in relation to climate (Fig. 5) showed that trees not only respond to climate at the annual timescale. Precipitation positively influences high-altitude spruce and low-altitude fir for a longer period. Temperature reduces growth of low-altitude fir, whereas it favors growth of high-altitude fir. A long-term influence of climate events on tree growth has been found also in other studies (Bouriaud & Popa 2009, LaMarche 1974, Mäkinen et al. 2002, Peterson & Peterson 2001). In the Black Forest, Kahle and Spiecker (1996) correlated growth of spruce with evapotranspiration and water balance from April till September with lags of 4 years. Strongest correlations were found with climate factors in the year preceding growth, but significant correlations with up to 4 years time lag were observed. In the Vosges Mountains, Becker (1989) found that growth of silver fir was affected by climate factors as far back as 6 years. These findings may be partly related to needle retention. As fir and spruce retain their needles for several years, severe stress can negatively influence the photosynthetic activity or even cause needle-loss reducing tree-growth for a longer period of time (Fritts 1976, LaMarche 1974).

In addition, the pointer year analysis provided deeper insight in climate-growth relationships in extreme years (Fig. 6). The occurrence of extreme tree-rings depends on factors like climate, species, altitude and aspect (e.g. Desplanque et al. 1999, Lingg 1986), but the causes are not always directly explicable. We found narrow rings in 1948 in high-altitude fir and in 60% of high-altitude spruce trees at south- to southwest-exposed sites. This growth depression may be related to the drought in 1947 (Rolland et al. 2000, Becker et al. 1990). However, it might also be a result of the below-average temperatures in June and July 1948 (Desplanque et al. 1999, Kindermann & Neumann 2011, Neuwirth et al. 2004), or a combination of both (Dittmar & Elling 1999).

The percentage of trees having a pointer year in 1976 was highest for low-altitude fir in this study, which was observed in several alpine valleys in France as well (Desplanque et al. 1999, Rolland et al. 2000). However, also high-altitude fir trees showed a growth depression, in accordance with findings by Spiecker (1986) and Kahle (1996). Few high-altitude spruce trees showed a strong

growth reduction, as they could probably profit from precipitation in June (Schweingruber & Nogler 2003).

In 2003, a year with less precipitation and much higher temperatures compared to 1976, many low-altitude fir trees experienced a growth depression, but not as extreme as in high-altitude spruce, whereas less than 50% of the high-altitude fir trees showed a strong growth depression. The difference in reaction between high-altitude fir and spruce may be related to the deep taproot of fir. This taproot makes it possible to reach water sources in deeper soil layers (Lingg 1986). Further, in contrast to 1976, 2003 followed years that were sufficiently wet. Preconditioning of tree vigor in previous years has been found to reduce negative growth effects on drought-exposed forest trees (Pichler & Oberhuber 2007).

The widespread pointer year in 2006 may be a result of low precipitation in June and July in combination with high temperatures and lagged effects of dry conditions in preceding years. Besides, 2006 was a mast year (Meining & von Wilpert 2006), which may have caused carbohydrates to be allocated to seed production instead of diameter growth. Several studies observed reduced diameter and/or height growth of spruce due to fructification (Aichmüller 1962, Dohrenbusch et al. 2002, Rohmeder 1967). However, Seifert and Müller-Starck (2009) observed no trade-off between cone production and stem biomass growth in fructifying spruce trees in Bavaria between 2003 and 2006. For silver fir, no studies on the impact of fructification and diameter growth are known.

The pointer year analysis also revealed a high sensitivity of high-altitude fir for winter frost. We found growth depressions as a result of extremely low temperatures in 1940, 1956 and 1987. In the Black Forest, Gerecke (1988) and Schweingruber and Nogler (2003) also observed narrow rings in 1940 and 1956 in fir. Studies in France documented 1956 as a negative pointer year as well, but found 1986 instead of 1987 as a year with growth depressions after a frost event (Lebourgeois et al. 2010, Lebourgeois 2007, Desplanque et al. 1999, Rolland et al. 2000). Negative effects of low winter temperatures on growth of fir where also found using correlation or response function analysis (Bouriaud & Popa 2009, Frank & Esper 2005, Rolland et al. 1999).

Conclusions

Our findings indicate that low-altitude fir and high-altitude spruce at southwest-exposed sites in the Black Forest are vulnerable to drought during the growing season and the year prior to growth. Warming will lead to increased evapotranspiration rates, which may negatively affect tree growth if water deficits are not compensated by increased precipitation. We found a positive effect of current temperature and a negative effect of current precipitation on growth of high-altitude fir. However, the timing or magnitude of heat waves and periods with low precipitation might still cause growth depressions in high-altitude fir, as observed in 1976 and 2003. Studies on intra-annual wood characteristics, such as cell parameters (Park & Spiecker 2005) and wood density (Bouriaud et al. 2005, Martinez-Meier et al. 2008, Jyske et al. 2010), may provide more in-depth information about effects of extreme climate conditions on growth of fir and spruce in the Black Forest region.

Acknowledgements

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A 409 year precipitation record derived from Upper Silesian pine chronologies

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Introduction

Upper Silesia is one of the regions in Poland with very few historical climate studies, despite conducting meteorological observations from the early 19th century and the existence of potential sources of proxy data. In recent years some studies have been carried out with the use of historical data only (Długajczyk 2009, Czaja 2010). However, the abundant dendrochronological materials of this region remained so far unexploited for reconstructing climate purposes. Particular historical tree ring data-sets potentially represent a significant archival source for historical climate investigations as shown by previous studies (e.g. Brazdil et al. 2002, Wilson et al. 2004, Hoffmann et al. 2009, Büntgen et al. 2010, Tegel et al. 2010). The employment and combination of annually resolved historical records and natural proxy data (tree rings) provides the possibility of extending instrumental station records back in time. The objective of this study was to obtain long, composite tree-ring chronology of pine from the Upper Silesia and to determine its suitability as climate archive.

Study area and its climate

Study area is situated in the southern Poland, the eastern part of Silesian Lowlands, Opole Voivodeship (Fig. 1). This is wide plain with mean height about 100-260 m above sea. Upper Silesia forests are dominated by *Pinus sylvestris.* Field work was done in the oldest pine stands, which are protected in nature preserves, as remains of Silesian Primeval Forest. Pine wood is also often found in numerous wood construction in this area, which are remnants of old rural buildings.
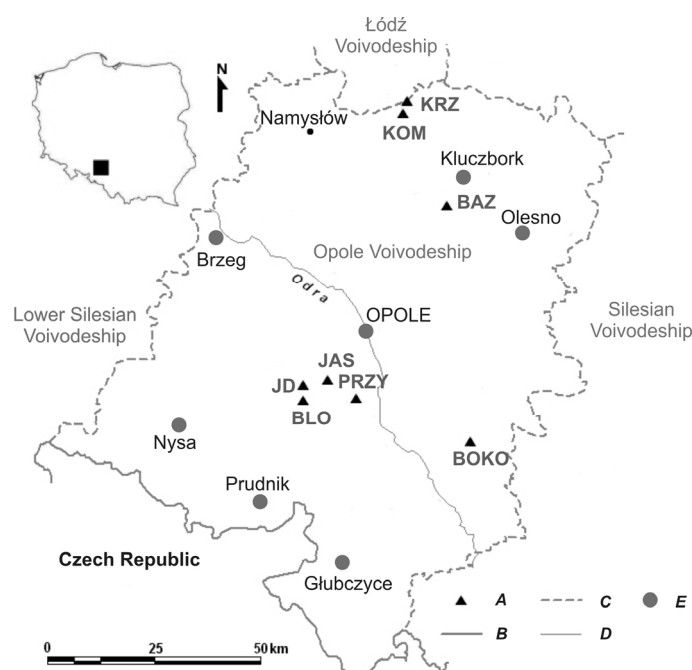
Figure 1: Location of research area. A – sampling sites, B - state border, C - boundaries of provinces, D – rivers, E - meteorological stations

Climate of the study area is one of the warmest in Poland, under the influence of oceanic air. The mean annual air temperature in Opole is 8.7°C (1900-2000), ranging from −1.3°C in January to 18.7°C in July. The annual amount of precipitation is 610 mm. Characteristic features of the climate are also short winters, early springs, warm summers and long growing seasons.
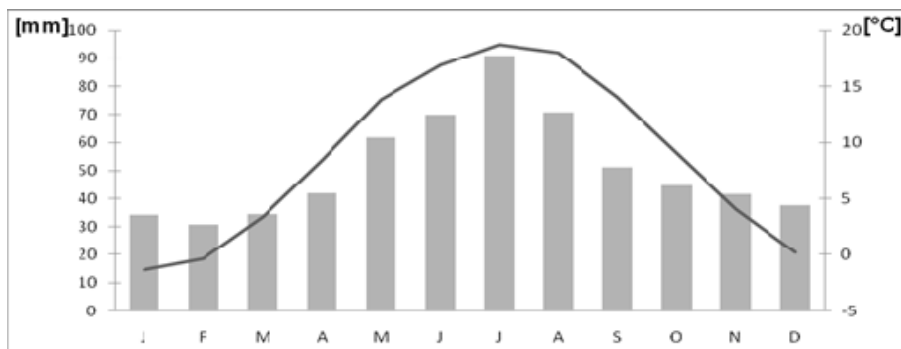
Figure 2: Air temperature (°C) and precipitation (mm) from the meteorological station in Opole (1900-2009)
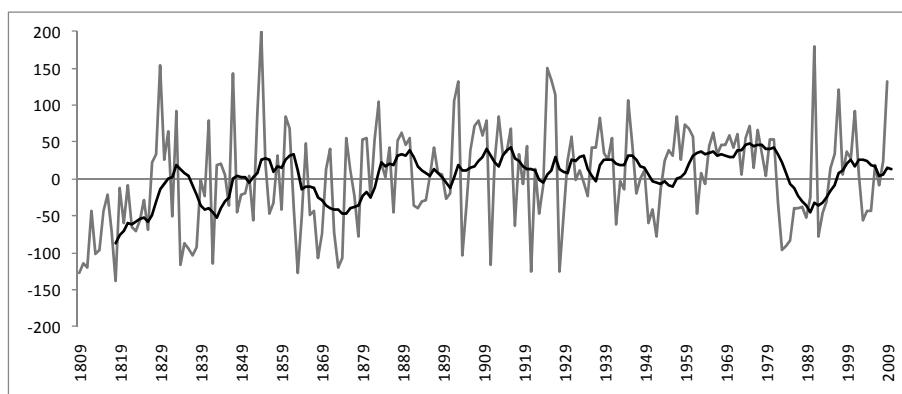
Figure 3: Summer (June-July) instrumental precipitation data (mean of ten meteorological stations) expressed as anomalies with respect to 1971-1990

Material and methods

Wood material

Figure 4: Sources of wood material: A –monumental wooden structures in the Opole Open-Air Museum of Rural Architecture (Granary from Murów, XIX century); B – "Przysiecz" nature reserve

Dendrochronological material was collected in seven nature preserves (Fig.1, Tab. 1), in which 150 cores of Scots pine were obtained. The study also includes historical timber. Sampling was

conducted in the Opole Open-Air Museum of Rural Architecture, which collects the oldest wooden buildings from the historic Upper Silesia. A total of 350 historical wood samples were analyzed. For both the living trees and wooden structures cores were the principal research material. Site and regional chronologies were constructed according to the conventional procedures. Historical timbers were dated visually and the synchronisation was checked with COFECHA program.

Table 1: Characteristics of the sampling sites

Site code	Site name	Location	Elevation (m asl)	Number of cores
BAZ	"Bażany" nature reserve	50°55/18°10	202	16
BLO	"Blok" nature res.	50°31/17°43	205	20
BOKO	"Boże Oko" nature res.	50°27/18°15	316	19
JAS	"Jaśkowice" nature res.	50°34/17°47	212	27
JD	"Jeleni Dwór" nature res.	50°30/17°43	190	15
KOM	"Komorzno" nature res.	51°07/18°01	210	15
KRZ	"Krzywiczyny" nature res.	51°06/18°02	205	15
OLE	Forest Inspect. Olesno	50°55/18°22	217	24
HIST	Open-Air Museum	51°02/17°14-50°25/18°31	190 – 220	350

Pointer year analysis was carried out to determine years in which conspicuously smaller or larger increment occurred as the result of favourable or detrimental environmental (meteorological) factors. Calculations of the pointer years were performed on the raw data sets in WEISER program, pointer years were identified from at least 10 trees, and the minimum convergence threshold was set at 80%.

Instrumental and documentary data

Meteorological data (monthly average air temperatures and sums of atmospheric rainfall) for XIX and XX century, from ten meteorological stations from Silesia (Tab. 2.) were taken from the archival German Meteorological Yearbooks (Deutsches Meteorologisches Jahrbuch 1935-1945, Ergebnisse der Meteorologischen Beobachtungen 1885-1923), Polish Institute of Meteorology and Water Management Meteorological and Precipitation Annals and Monthly Weather Reviews (Roczniki IMGW, Miesięczny przegląd pogody), and also from other available sources (Galle 1857, Hellmann 1906, Klimakunde des Deutschen Reiches 1939). Climatic response was evaluated by bootstrapped correlations between residual TRW series and monthly mean temperatures and precipitation sums (average of 10 stations). Calculations were performed for various time intervals with DENDROCLIM2002 software.
Documentary data derived from studies of archival sources performed by Namaczyńska (1937), Inglot (1962, 1986), Rojecki (1965) and Kwak (1987), were used for pointer years explanation.

Table 2: Characteristics of the instrumental data

Station	Latitude	Longitude	Elevation (m asl)	T-record	P-record
Bytom (Beuthen)	50°21	18°55	292 – 300	1885 – 1965	1875 – 1981
Gliwice (Gleiwitz)	50°16	18°40	220 – 246	-	1899 – 1981
Głubczyce (Leobschütz)	50°20	17°80	357 – 290	1805 – 1981	1833 – 1981
Głuchołazy (Ziegenhals)	50°18	17°23	285 – 345	1949 – 1981	1900 – 1981
Katowice (Kattowitz)	50°14	19°02	286	1945 – 2009	1930 – 2009
Kluczbork (Kreuzburg)	50°58	18°12	180	1823 – 1850	1834 – 1981
Olesno (Rosenberg)	50°53	18°26	238 – 240	1919 – 1977	1887 – 1981
Opole (Oppeln)	50°40	17°55	163 – 175	1885 – 2009	1878 – 2009
Racibórz (Ratibor)	50°60	18°13	189 – 196	1885 – 2009	1848 – 1981
Wrocław (Breslau)	51°07	17°03	116 – 147	1799 – 2009	1799 – 2009

Tree-ring chronologies

Site chronologies

Eight site chronologies from living trees have been constructed (information on chronologies and their parameters in table 3). All chronologies are composed of at least 15 samples. The longest chronology covering the period 1767-2009 were constructed for "Komorzno" nature reserve. Mean tree-ring width of series was quite similar in six chronologies, ranging from 1.13 to 1.75 mm. Significantly larger increments were formed by the trees in "Bażany" (3.03 mm) and "Olesno" (2.07 mm) sites. Mean sensitivity range from 0.23 to 0.29 and running Expressed Population Signal index value range from 0.75 to 0.93 within the sites. Similarity (GI% and t-value) calculated between site chronologies and Silesian master chronology shows significant differences in growth curve course in two sites: "Boże Oko" and "Bażany".

Table 3: Characteristics of the sites chronologies

Chronology code	Samples replication	Time span >5	Mean segment length	Average growth rate (mm)	EPS	Mean sensitivity	Similarity with Silesian master chronology	
							GI %	T-value
BAZ	16	1930-2010 (80)	77	3,03	0,81	0,229	62	3,7
BLO	20	1793-2010 (217)	188	1,13	0,93	0,224	75	13,8
BOKO	19	1848-2007 (159)	117	1,75	0,79	0,262	48	2,2
JAS	27	1815-2009 (194)	156	1,43	0,86	0,275	80	13,4
JD	15	1850-2010 (160)	157	1,54	0,87	0,244	75	13,1
KOM	15	1767-2009 (242)	164	1,29	0,75	0,274	71	7,8
KRZ	15	1833-2009 (176)	155	1,41	0,86	0,286	76	9,0
OLE	24	1913-2009 (96)	91	2,07	0,92	0,229	82	9,8

Regional chronology

443-years composite chronology including about 200 samples from living and historic wood covers the AD 1568-2010 period. Dendrochronological dating of samples is shown in figure 4. Mean series intercorrelation is 0.506, average mean sensitivity is 0.24. Reasonable signal strength is found for past 300 years, as demonstrated by the EPS value (>0,85 until ~1710) (Fig. 6.).
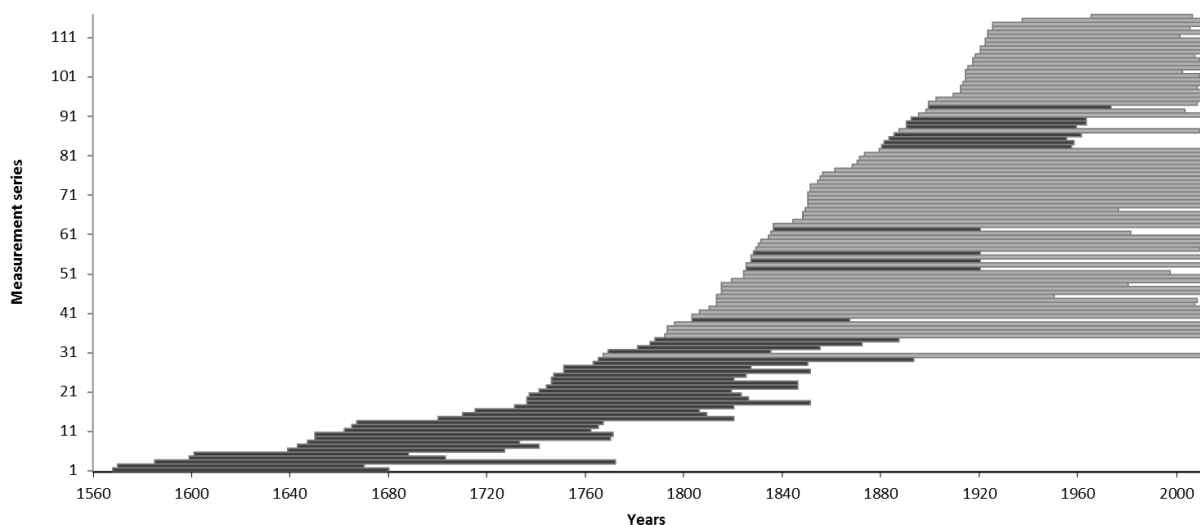
Figure 5: Dendrochronological dating of growth sequences of samples from living trees (light grey bars) and from historical wood (dark grey bars)
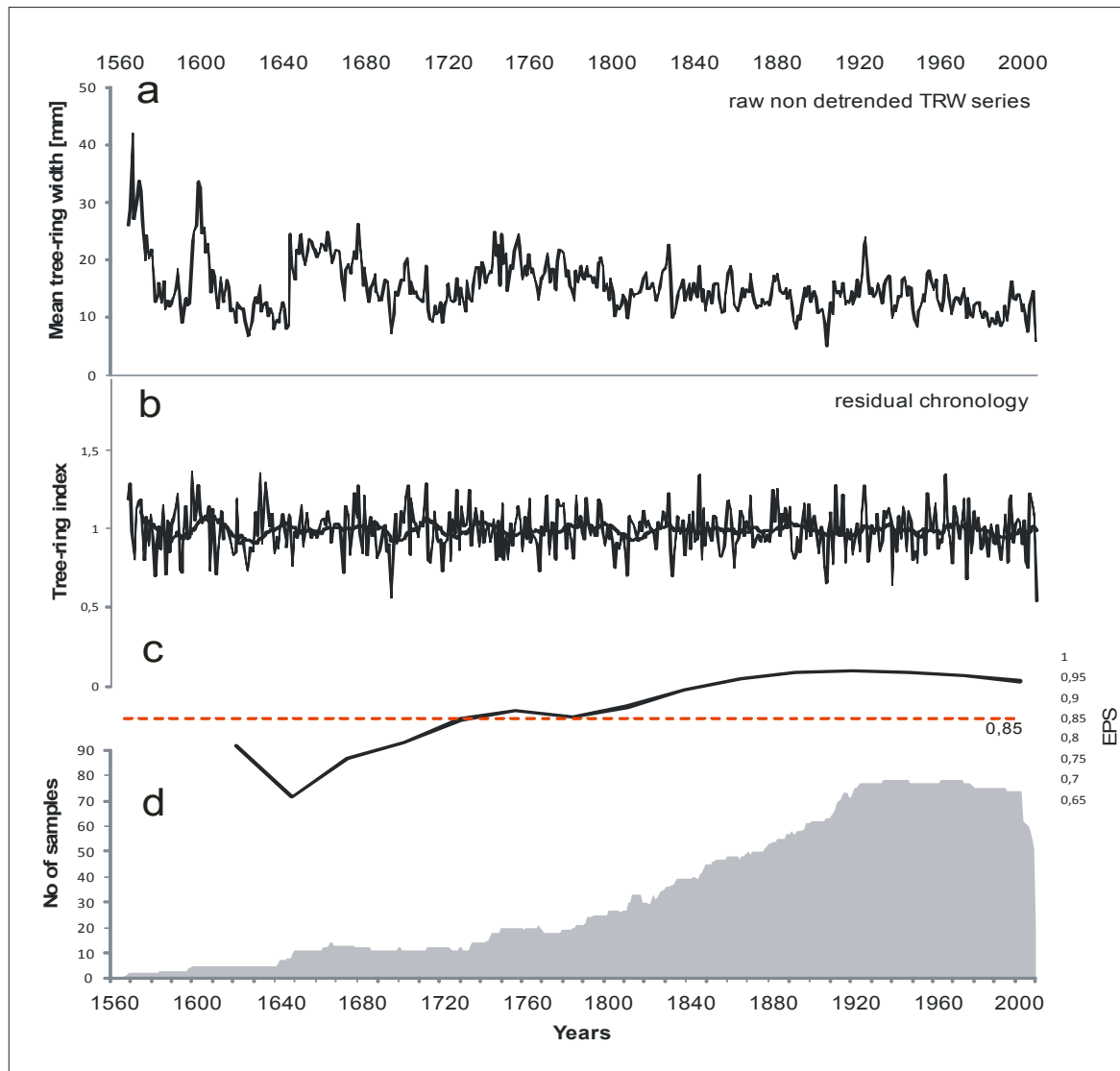
Figure 6: Comparison of the (a) raw tree-ring values, (b) residual Silesian pine chronology and its (c) EPS and (d) replication

Dendroclimatological analysis

Tree-ring climate relationship
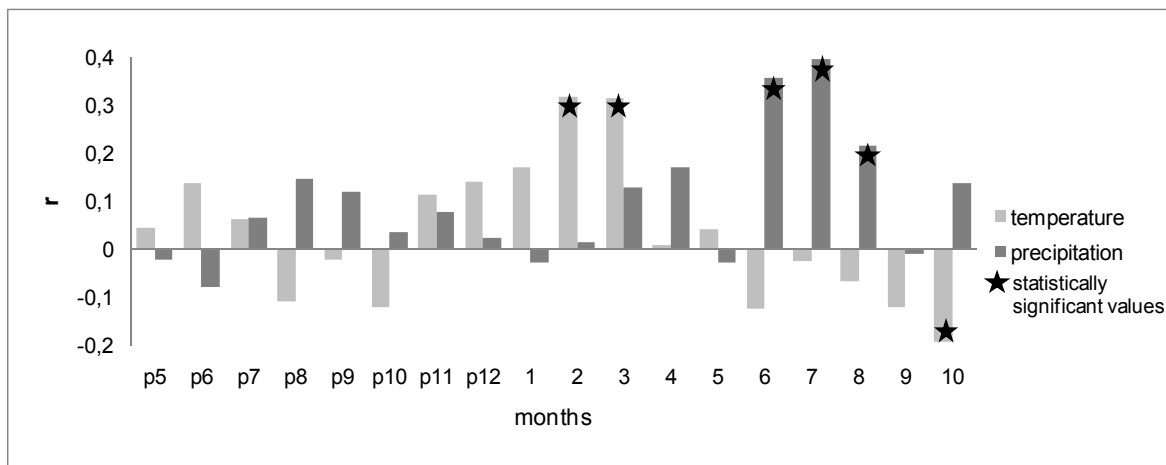
Figure 7: Results of correlation between climate parameters and SILESIAN chronology calculated for period 1852-2009 (CC significant at the 95% confidence level marked with an asterisk)

The most significant influence on the annual ring of pine formation in this area are primarily summer rainfall (CC=0,4 for June and July), and the temperature of winter months (CC=0,3 for February and March). These dependencies are time stable for SILESIAN chronology, but vary over time when calculated for site chronologies. At some sites temporal weakening in the climate/growth response can be observed in the most recent part of this chronologies.

Pointer years analysis

Table 4: Selected years of exceptionally wide and narrow annual pine increments in Upper Silesia (US), from the XVII to the XX century compared with the historical and instrumental data (monthly and seasonal precipitation totals are expressed in percentage of the 1961–1990 reference period)

| Pointer years		Description of weather and comparison with meteorological measurements	source
Negative	Positive		
1673		*"From 1670 for three consecutive years, wet winter and all year, wet harvest, the autumn floods, frequent flooding of rivers, prevent the harvest of cereals and sowings, late sowing of winter crops..."*	*documentary data*
	1688	*Upper Silesia: "Summer is very rainy and wet, rain falling continuously throughout the summer, causing significant flooding of rivers."*	
1696		*Poland: severe and long winter (October to April 1695/1696)*	
	1704	*No interpretable report*	
	1713	*US: third consecutive wet year, the spring flooding of the Oder. Moravia: wet year, frequent rains*	
1715		*No interpretable report*	
1716		*No interpretable report*	
1721		*US and Moravia: Great drought (also in 1720 and 1719)*	
	1728	*US: wet year*	
1729		*US: spring frosts*	
	1734	*US: wet year*	
1753		*Moravia: great drought in summer*	
	1758	*No interpretable report*	
1760		*US: drought in 1759*	
1768		*US: spring frosts*	
1785		*US: cold winter, great flood*	
1811		*US: drought, hot summer with temperatures reaching 38 degrees; drought also in Slovakia, Czech Lands, eastern Austria*	
1833		*US: high temperatures in June*	
1834		*US: drought*	
	1846	*US: two monthly excess moisture in the district of Opole*	
1858		Southern Poland: driest year (432mm), dry June	*instrumental data*
	1861	*US*: high rainfall in summer 133 %	
	1871	*US*: high rainfall in June 203 %	
1907		*US*: dry spring (May)	
1908		*US*: dry spring, low rainfall in June 57 %	
	1912	*US*: very wet July and August 187 %, Southern Poland: wet year	
	1927	*US*: wet summers in 1926, 1927, Slovakia: wet spring and summer	
1940		*US*: very frosty January and February	
1952		*US*: July rainfall 35%, S Poland: spring-summer drought in 1951 and 1952	
1964		*US*: June rainfall 49%, September rainfall 30%, drought in winter and spring; also in Slovakia	
	1966	*US*: downpours in July	
1969		*US*: July rainfall 16%, S Poland: winter-spring and summer drought	
1976		*US*: drought in spring and in June (rainfall 27%)	
2006		Poland: catastrophic drought in June and July (rainfall 26%)	

34 pointer years were identified and explained by documentary and instrumental data (Tab. 3). Negative pointer years were mainly associated with droughts and positive - with higher then average annual or summer precipitation. On the basis of the chronology of pine from Upper Silesia, including the last four centuries, increase in the incidence of pointer years can be observed in the periods: 1645-1720, 1834-1876, 1940-1976. The first highlighted period, known in the literature as Maunder Minimum, was characterized by the occurrence of 11 pointer years, and in the light of historical records is a period of consecutive particularly wet years (Tab. 4.). The period 1834-1876 was characterized by frequent occurrence of summer drought, strongest in 1834, 1858, 1876. According to dendrochronological and meteorological data droughts in the Upper Silesia also occurred in 1900, 1908, 1930, 1969, 1976, 2006. While periods of the positive years (wet) occurred at the turn of the eighteenth and nineteenth centuries, in the 20s of the nineteenth century and in 1861, 1871, 1912, 1986 and 2001. Extremely cold and long winters causing formation of a very narrow annual growth, occurred during the analyzed period only four times, in 1780, 1785, 1940 and 1996.

Conclusions

The regional chronology of pine may be used to reconstruct the precipitation conditions during summer months in the last three centuries, as shown by chronology parameters and dendroclimatological analysis. Although the trees from Upper Silesia are most commonly used as markers of human impacts on the environment, they can also be used as reliable archives of climate change in recent centuries complementing the other proxy and instrumental climate data.

Acknowledgements

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Growth-climate responses of oak and juniper trees in different exposures of the Alborz Mountains, northern Iran

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Introduction

Iran is in large parts a semiarid to arid country that is especially vulnerable to climatic change (Amiri and Eslamian 2010). Due to an increase in minimum air temperatures, relative humidity is decreasing in most parts of Iran (Kousari et al. 2011). Although precipitation trends vary spatially in different regions, most areas in Iran show decreasing trends of annual precipitation during the last decades (Modarres and Sarhadi 2009; Rahimzadeh et al. 2009), but these trends are spatially inconsistent. To derive better estimates on the long term climatic development of Iran, climate reconstructions based on high-resolution proxy data are necessary.

Despite of the lush forests covering the Alborz Mountains in northern Iran (Sagheb-Talebi et al. 2004; Knapp 2005), only few dendroecological studies have been carried out so far. First studies (Lipschitz et al. 1979; Shahi et al. 2005; Pourtahmasi et al. 2007, 2011; Oladi 2010) indicate the huge potential of the region for dendroecological analyses in juniper and beech forests. On the northern slopes of the eastern Alborz Mountains facing towards the Caspian Sea, existing forest types are clearly aligned along an altitudinal gradient. Above a broadleaved mixed forest containing many relict floral elements from the Tertiary period (Knapp 2005; Ramezani et al. 2008), a belt of Oriental beech (*Fagus orientalis*) forms a dense belt of cloud forests between ca. 800-2000 m m a.s.l. The uppermost forest belt up to ca. 2400 m elevation is formed by open mixed stands with *Carpinus orientalis, Acer spp.* and *Quercus macranthera* on north-facing slopes, whereas south-facing slopes oriented towards the inner valleys of the Alborz Mountains are covered by steppe forests of *Juniperus polycarpos*. The northern part of Iran mainly receives precipitation from western disturbances. The Caspian Sea has a strong influence on the regional rainfall patterns along its southwestern coast (Alijani and Harman 1985; Modarres and Sarhadi 2009), but this influence is fading out towards the east. Since very few climate data from Iran are available before 1950, long-term changes in precipitation and temperature have to be inferred from climate archives like tree rings.

However, little is known about the sensitivity of different tree species of the Caspian forest to climate and on the impact of exposure on climate-growth relationships. To evaluate the potential of two important tree species for climate reconstruction, we established new ring width chronologies from *Q. macranthera* and *J. polycarpos* and calculated climate-growth relationships.

Material and Methods

The study sites are located in the eastern Alborz Mountain range in northern Iran, south of the city of Gorgan (Table 1). We collected 20 increment cores from 15 oak and 74 cores from 39 juniper trees with a Swedish increment corer. The tree stands are generally open with a crown coverage of ca. 10%. Grazing indicators like thorny cushion plants are very common in both the juniper and the oak forest, respectively. Most oak trees were rotten in the center and showed sign of human disturbance, like cut branches. The two study sites are only ca. 2 km away from each other, yet experience different climatic conditions: the oak site is on a north-facing slope that is exposed to clouds that are driven from the Caspian Sea towards the south. The juniper forest is exposed

towards the south and is separated from the oak forest by a steep cliff that prevents the site from clouds. Thus, the juniper forest is exposed to higher solar irradiation and higher evapotranspiration. Recently, a local climate station has been set up to detect local climate characteristics at the study site in detail.

Table 1: Statistical parameters of carbon isotope chronologies of studied trees fom the locations Asco, Ballone and Capanelle. r = Pearsons correlation coefficient, Glk = Gleichläufigkeits-value

Site name	species	location	elevation	trees / cores	Total period	EPS>0.85
Gorgan	*Quercus macranthera*	36°40'N/ 54°33'E	2250 m	15 / 20	1597-2004	1925
Chaharbagh	*Juniperus polycarpos*	36°40'N/ 54°32'E	2500 m	39 / 68	1512-2007	1537

After smoothing the cores with a razor blade and contrasting the ring structures with chalk, ring widths were measured with a LINTAB system (Rinntech, Germany) to the nearest 0.01 mm. To remove the biological age trend in the tree-ring data, the raw values were power transformed and detrended by subtracting a cubic smoothing spline preserving 50% of low frequencies at 2/3rds of the series lengths (Cook and Peters 1997). To emphasize high-frequency variability in the chronology and to suppress long-term variations, we used the residual chronologies that are free of autocorrelation for further analyses. Climate-growth relationships were calculated as Pearson correlation coefficients of ring-width index chronologies and climate data from Gorgan climate station (36°51'N, 54°16'E; 13 m a.s.l.), which is the nearest to our study site (ca. 40 km distance). Since no climate data are available before 1954, we refrain from testing the temporal stability of climate-growth relationships and use the full data (1955-2004) to get a robust estimation of the climate factors affecting tree growth of both studied species.

Results

We were able to establish more than 400-year long ring-width series for both studied tree species (Table 1, Figure 1). For the period 1601-2000 (400 years), both chronologies show no common long-term variations and are only weakly correlated with each other ($r = 0.22$; $p < 0.05$; sign test = 58%, t-value after Bailie/Pilcher = 2.4). Before the 20th century, some ring-width curves showed individual growth reductions resulting by disturbance probably be cutting of branches, although they synchronized well with the site chronology. Resulting from such disturbances, the expressed population signal (EPS) of the oak chronology is considerably smaller than that of the junipers and a high sampling replication is required to exceed the recommended threshold of 0.85 (Wigley et al. 1984; Table 1). For the period 1953-2002 (50 years), the two chronologies are not correlated at all ($r = 0.135$; $p > 0.05$). This might indicate that the two tree species are exposed to different climatic conditions and that tree growth is limited by different climatic features at the two sites.
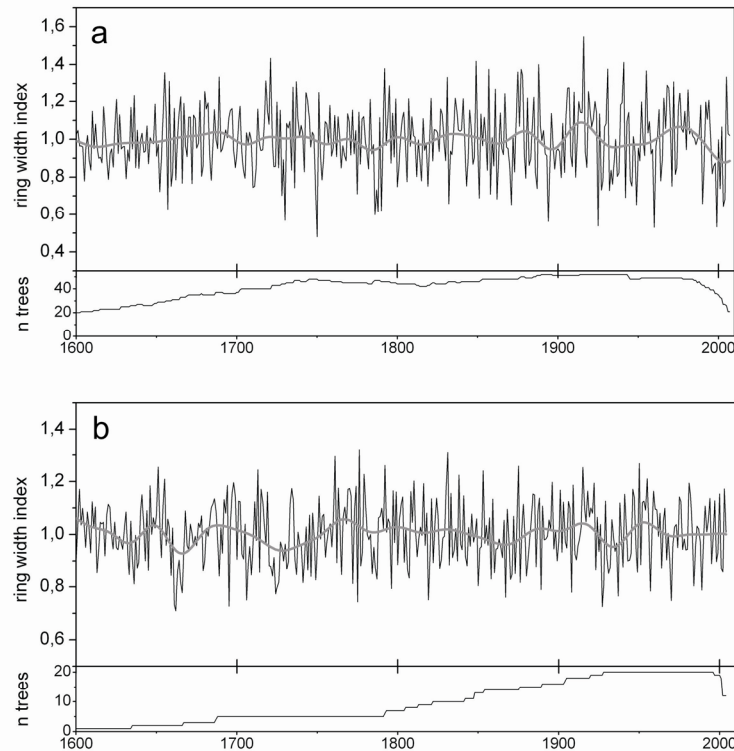
Figure 1: Residual ring-width chronologies (upper graphs) and their sample replication (lower graphs) for Juniperus polycarpos (a) and Quercus macranthera (b) in the northeastern Alborz Mountains, Iran. Bold curves indicate smoothed values by an 11-year FFT-filter.

The two tree species show a different reaction to climatic conditions (Figure 2): ring width of juniper is significantly (p>0.05) positively influenced by precipitation in spring (May), whereas oak is positively correlated with temperature in January, during autumn of the previous year and during July and August of the growth year, but shows no positive correlation to precipitation. In general, the correlations of both chronologies with monthly climate variables are rather weak which might be a result of the elevation differences of the studied sites and the location of Gorgan climate station. We also tested correlations with the global dataset of the Palmer Drought Severity Index (PDSI, Dai et al. 2004) and found a highly significant correlation of the juniper chronology with the PDSI during the summer (May-October) season (r = 0.42, p>0.01; grid point at 36,25°N; 56,25°E), whereas ring width of oak did not show any correlation with local PDSI.
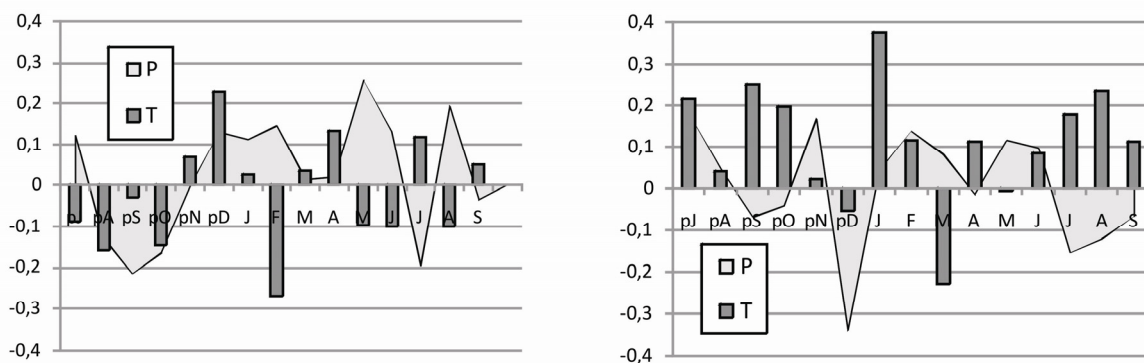
Figure 2: Correlation function of juniper (left) and oak (right) chronologies from northern Iran with temperature and precipitation data from Gorgan meteorological station.

Discussion and conclusions

Our first results indicate the possibility to establish long, climate-sensitive tree-ring chronologies from northern Iran. The positive correlation of the juniper chronology with local precipitation at Gorgan and PDSI during the spring and summer months demonstrates that growth rates at this dry site are limited by moisture conditions. Thus, the *Juniperus polycarpos* at semiarid, high-elevation tree-ring sites in northern Iran offer the potential to reconstruct former precipitation variations. In contrast, growth rates of *Quercus macranthera* do not indicate a limiting influence of moisture availability at north-exposed high-elevation sites, but show a positive influence of temperatures during previous autumn, winter and summer on growth. Thus, the combination of both tree species might offer the possibility to reconstruct different climatic parameters. We intend to test if additional tree-ring parameters, such as stable carbon and oxygen isotopes and wood anatomical parameters in oak, show stronger correlation with local climate data than ring width. Finally, we attempt to reconstruct regional moisture and temperature variations of northern Iran during the past ca. 400 years.

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Climate signals in carbon isotope series from *Pinus nigra* ssp. *laricio* in Corsica

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Introduction

The Mediterranean is considererd as one of the hotspots of future climate change since a northward shift of subtropical anticyclones is predicted to result in pronounced drought stress during summer months (IPCC 2007; Gao & Giorgi 2008). For an evaluation of future climate changes, however, knowledge about past climate conditions is crucial. A promising climate archive are pine trees (*Pinus nigra* ssp. *laricio*) growing on the island of Corsica in the northwestern Mediterranean that may reach ages of up to 800 years. *Pinus nigra* ssp. *laricio* is abundant in the mountains and often form the upper tree line. Due to its steep relief with several peaks rising more than 2000 m asl, Corsica hosts a large variety of different local climate conditions within a distance of only a few kilometers. The typical Mediterranean climate with mild wet winters and dry hot summers can be found along the coast line (see Fig. 1 for climate diagram for Ajaccio). Precipitation increases with altitude (from around 600 mm/a at the coast up to more than 1500 mm/a at 1000 m asl) whereas temperature decreases in higher altitudes. However, precipitation and temperature may vary significantly within individual mountain ranges (Bruno et al. 2001; Kuhlemann et al. 2008). An example for a dry mountain region is the high valley of Niolo represented by the climate station Calacuccia (Fig 1).

Since carbon isotopes from trees in regions, including dry mountain environments, often show strong correlations with July and August precipitation (Anderson et al. 1998; Treydte et al. 2001; Gagen et al. 2004), the isotope ratios can be used for the reconstruction of late summer climatic conditions. The aim of this study is to evaluate the local climate signal derived from 100 year long carbon isotope series from *Pinus nigra* from three Corsican mountain sites.

Study sites

The three study sites are located in the main mountain range of Corsica. Two sites are situated in the northern and one in the central part of the island (Fig. 1). The site Asco (1500 m asl) is located in the headwaters of an east-west striking valley north of Monte Cinto, which represents the highest peak of Corsica (2706 m asl). The valley is sheltered against westerly winds by the main mountain range. Local climate is relatively cold and dry compared to other mountain sites with snow being the main precipitation type in winter. Trees were sampled at the upper tree line which consists exclusively of *Pinus nigra*. The site Ballone is located in a side valley of the dry Niolo high valley at the southern slopes of Monte Cinto. Studied *Pinus nigra* trees form the upper tree line (1600-1700 m asl) and grow on a steep slope with sparse vegetation cover. The local climate is warm and dry with more pronounced drought stress during summer months than at Asco. The third study site, Capannelle (1700 m asl), is located further south at the eastern slopes of the Monte Renoso Massif. In contrast to the other sites, two species, *Pinus nigra* and *Fagus sylvatica,* are growing at the upper tree line. Precipitation amounts are higher than at Asco and Ballone since air masses from the east coast affect the study site. Due to frequent fog occurrence, the local climate can be characterized as relatively cold and wet.
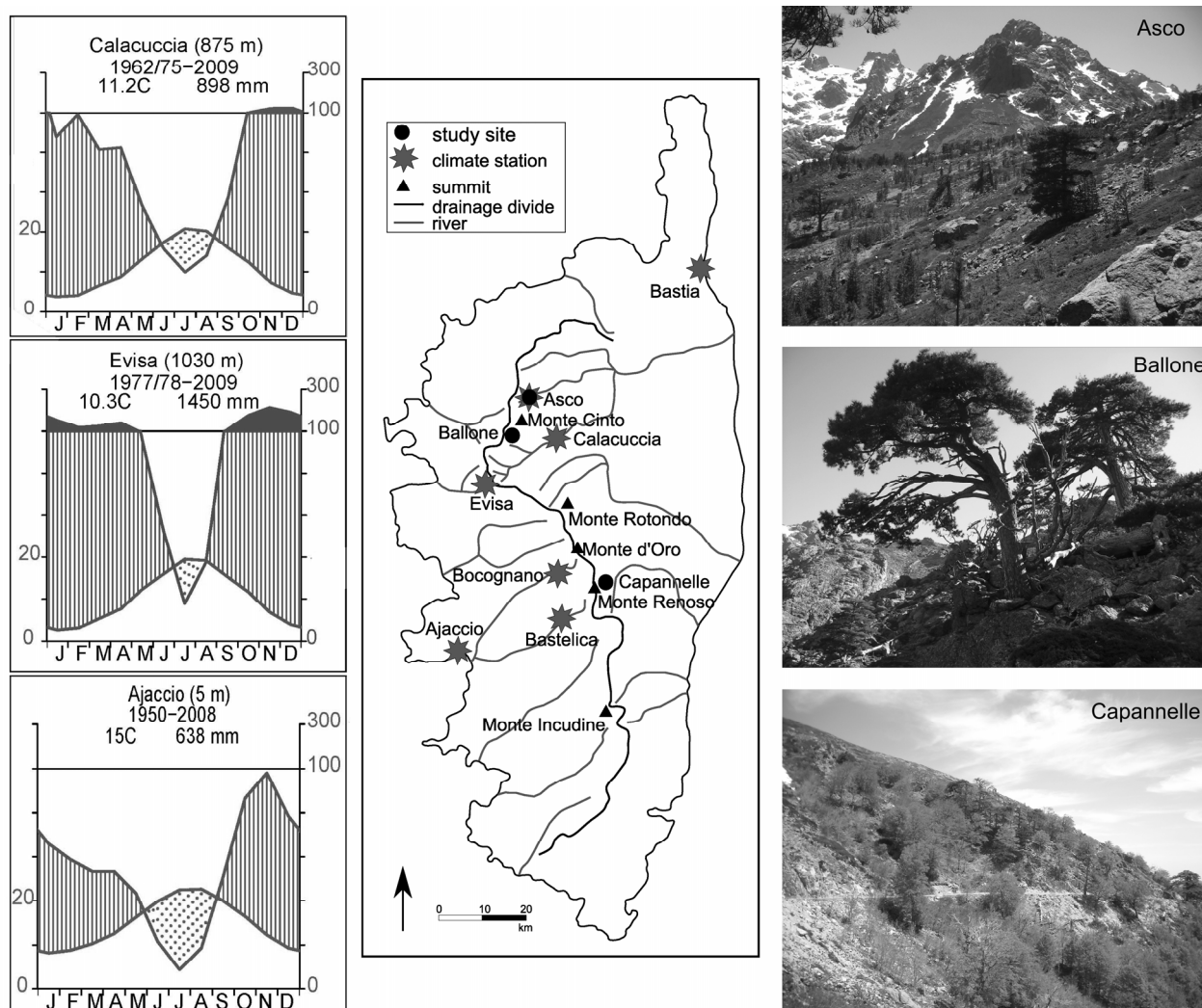
Figure 1: Location of study sites Asco, Ballone and Capanelle and climate diagrams for the stations Calacuccia, Evisa and Ajaccio.

Material and Methods

We cored 5-6 trees per site since this number is considered sufficient to represent the environmental conditions at a specific site (Treydte et al. 2001). Mean ages of sampled trees ranged from 698 years BP (Asco) to 388 years BP (Capannelle; Tab. 1). After dating and crossdating the tree cores with the program TSAP (Rinn 2008), tree rings were separated with a scalpel and one core from each tree was selected for the pooled sample. Pooling means the mixing of contemporaneous tree-ring material of several trees prior to cellulose extraction in order to reduce the number of samples and get a more representative signal for a specific site. Cellulose extraction was shown to be an important prerequiste for the development of isotope series from *Pinus nigra* trees (Szymczak et al. 2011). The extraction procedure followed the standard method of Kürschner & Popik (1962) and included the two steps delignification with acidified sodium chlorite (17%, 4h at 60°C) and alkaline hydrolysis with sodium hydroxide solution (7%, 36h at 60°C) to extract non-cellulose polysaccharides. Alpha-cellulose was homogenized using an ultrasonic homogenizer and freeze dried. Subsamples from each year were weighed into tin capsules and measured using a CE 1110 elemental analyser coupled online to a ThermoFisher Delta Plus mass spectrometer. Carbon isotope chronologies were corrected for the anthropogenic change in $\delta^{13}C$ of atmospheric CO_2 using the correction factors provided by McCarroll & Loader

(2004) and McCarroll et al. (2009). Correlations between carbon isotope values, mean monthly precipitation and mean monthly temperature for the last 30-40 years were calculated with the program DENDROCLIM 2002 (Biondi & Waikul 2004) using climate data from the mountain climate stations Asco, Calacuccia, Evisa, Bocognano and Bastelica (Météo-France 2010; for location of climate stations see Fig. 1). We used only mountain climate stations for calculation of climate-isotope relationships because these stations better represent climate at the study sites than coastal stations. Correlations were calculated for all study site with each climate station.

Table 1: Statistical parameters of carbon isotope chronologies of studied trees fom the locations Asco, Ballone and Capanelle. r = Pearsons correlation coefficient, Glk = Gleichläufigkeits-value

Site	No of trees	Mean tree age	Mean δ¹³C	Correlation	r	Glk
Asco (As)	6	698 (±111) years	-20.87 (±0.48)	**As-Ba**	0.10	60
Ballone (Ba)	6	500 (±82) years	-21.37 (±0.47)	**As-Ca**	-0.06	55
Capannelle (Ca)	5	388 (±46) years	-21.93 (±0.66)	**Ba-Ca**	0.46	60

Results

The three carbon isotope chronologies of the study sites covering the time period 1908-2008 (Fig. 2) show weak correlations and low Gleichläufigkeits-values (Tab. 1). Similarities in the carbon isotope chronologies are mirrored by low values in the years 1925, 1963 and 1996. Although corrected for the Suess Effect, a trend in decreasing $\delta^{13}C$ values is observed for the last 50 years, especially for the site Capannelle.
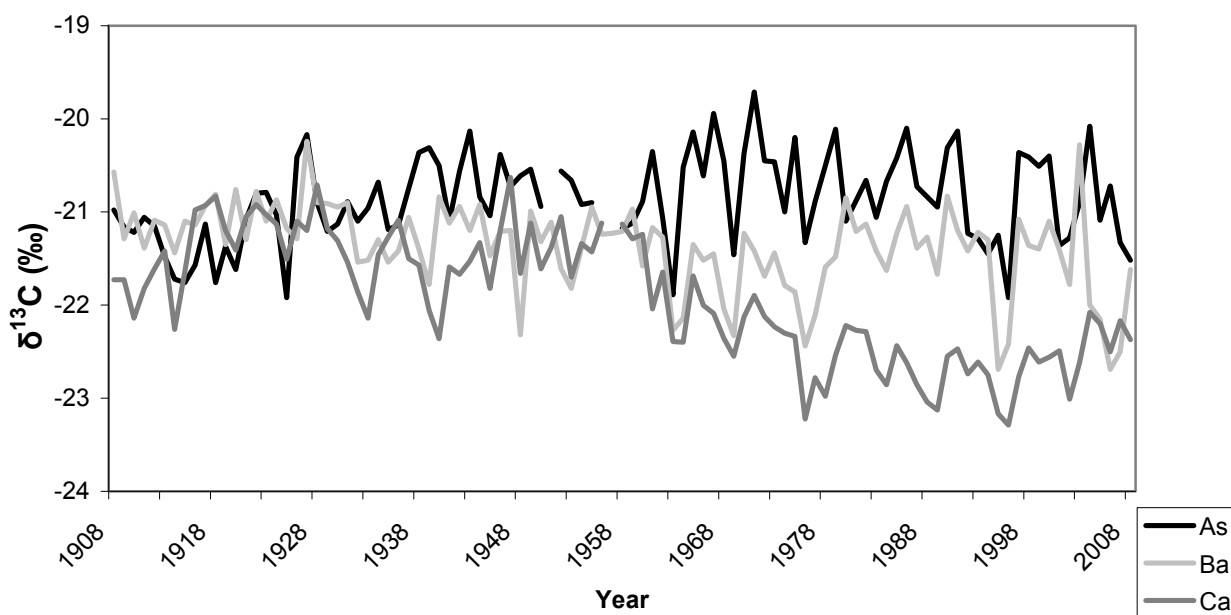
Figure 2: Carbon isotope chronologies of the three study sites Asco (As), Ballone (Ba) and Capannelle (Ca) for the time period 1908-2008.

Figure 3 reports only the strongest correlations between carbon isotopes and climate parameters which are significant with all or nearly all climate stations. Significant correlations with climate parameters for similar months indicate a similar effect of climate on stable carbon isotope fractionation at the three sites (Fig. 3). Carbon isotopes are mainly influenced by temperature and precipitation during the later months of the current vegetation period (August and September). Correlations between carbon isotopes and temperature are in general stronger than with

precipitation. The highest correlation is observed at the site Ballone between carbon isotopes and August temperature (r = 0.74). Carbon isotopes from Capannelle show the weakest correlations with the climatic conditions in late summer months.
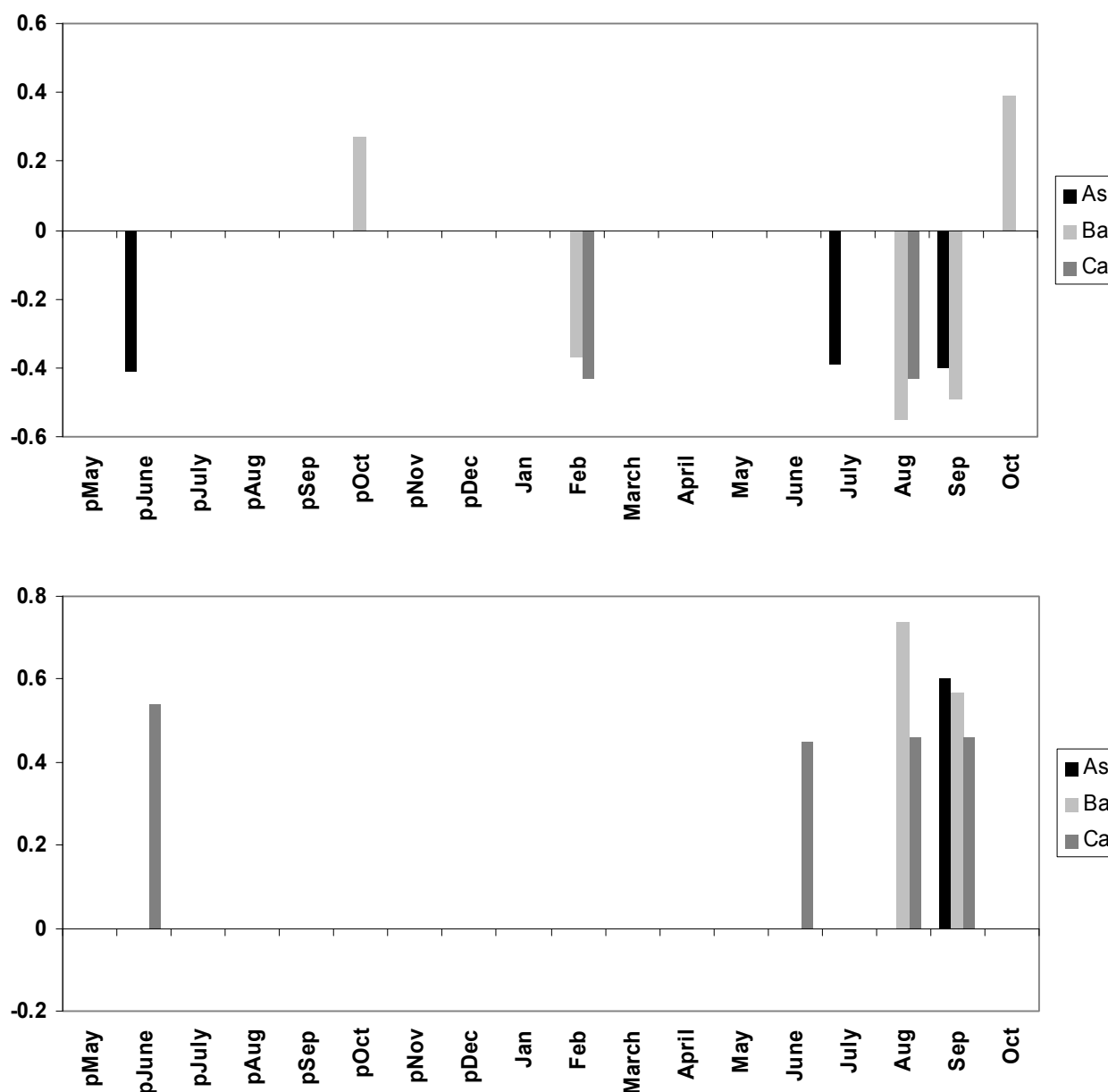
Figure 3: Pearson correlation coefficients between carbon isotopes, precipitation (above) and temperature (below) for the 18 month period from previous May (pMay) till October of the current year. Only significant correlations are shown (P<0.05). As: Asco, Ba: Ballone, Ca: Capannelle

Discussion

The study sites in the mountains of Corsica are characterized by a continuous snow layer from December to March. As single snow fields may even remain until May, i.e. the beginning of the vegetation period, water availability is not a limiting factor for tree growth during the early months of the vegetation period. Instead, water constraints may occur during summer (June-August) due to low precipitation. The sensitivity of *Pinus nigra* to summer precipitation is underlined by strong correlations between tree-ring width and summer precipitation.

Carbon isotopes of *Pinus nigra* trees are mainly influenced by conditions during the later months of the current vegetation period. A dry and warm summer results in high δ^{13}C-values because photosynthetic productivity is reduced in order to avoid an exhaustive water loss by reducing the openness of the stomata (Farquhar et al. 1989). In contrast, during a wet and cool summer, water loss is less severe with the stomata being open allowing a high rate of photosynthesis. This results in a high discrimination against ^{13}C resulting in low δ^{13}C-values in tree rings (Farquhar et al., 1989). Trees from Capannelle show considerable lower δ^{13}C values than trees from Asco and Ballone which can be attributed to the different microclimates. In a wetter and cooler climate, photosynthetic carbon isotope fractionation is higher than in a drier environment documented in the lower δ^{13}C values.

Beside the correlation with late summer climatic conditions, carbon isotope ratios are correlated with winter precipitation at two study sites. Winter precipitation will determine the thickness and duration of the snow cover and thus the soil moisture status at the beginning of the vegetation period. Soil moisture status in turn controls carbon isotope fixation via stomatal conductance (McCarroll & Loader 2004).

Although the three study sites show similar temperature-carbon isotope relationships, differences concerning the strength of the correlations and the time of the year occur. Asco shows significant correlations only in August, Ballone in August and September and Capannelle additional correlations with temperature of previous and current June. These variations can be explained by the local climatic conditions. Ballone is the driest site with most severe drought stress during summer months. At Ballone, drought stress may already start in August while at Asco drought stress only occurs in September. Drought stress is less pronounced at the wettest site, Capannelle, reflected by weaker correlations with temperature and precipitation. Instead, the duration of the vegetation period seems to influence the carbon isotope signature indicated by significant correlations with June temperature.

The carbon isotope chronologies are based on whole tree-ring cellulose samples. The analysis of separated latewood is not applicable as the latewood portion of the tree ring is often too narrow to allow an accurate separation. However, the climate-isotope relationship indicates that the carbon isotope signal is not influenced significantly by previous year conditions but mainly by the later months of the current vegetation period. Therefore, whole tree-ring cellulose yield valuable results which can be attributed to the year when the tree ring was formed.

Conclusions

Carbon isotope series of *Pinus nigra* trees from three different mountain sites on Corsica share a common climate signal but also allow detecting differences in local climate. Trees at drier sites react more sensitive to drought stress during late summer months than trees at wetter sites. The strong correlations between carbon isotopes and both, temperature and precipitation, emphasize the potential of carbon isotope chronologies derived from *Pinus nigra* spp. *laricio* tree rings for climate reconstructions in the western Mediterranean.

Acknowledgements

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ECOLOGY

A new sampling strategy for tree-ring based forest productivity estimates

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Introduction

Forests are a key component of the terrestrial carbon cycle (Bellassen et al. 2011) and serve as an important net carbon sink (Luyssaert et al. 2008). However, the strength of this sink varies from year-to-year and likely at lower frequencies in response to environmental fluctuations. Considerable efforts have recently been invested to assess and quantify environmental drivers of the carbon balance (e.g. Lindner et al. 2010) and its susceptibility to extreme climate events (Ciais et al. 2005). Thereby, most studies have been conducted using dynamic global vegetation models (DGVMs, Sitch et al. 2008) or carbon-flux measurements (e.g. Vesala et al. 2010). Empirical assessments of annual forest productivity are an ideal tool to validate and improve estimates of the large-scale terrestrial carbon budget. Yet, such investigations are rare and were mainly conducted on a local scale (e.g. Chiesi et al. 2005).

Annual radial growth is strongly linked to full tree woody biomass increment (Bouriaud et al. 2005) and thus is an ideal proxy for forest productivity. Numerous allometric volume and biomass equations have been developed for many species to estimate absolute annual increment from tree-ring width (Zianis et al. 2005). However, existing tree-ring networks have been collected to answer a plethora of scientific questions, such as climatic response (e.g. Frank & Esper 2005, Friedrichs et al. 2009, Affolter 2010), by a variety of different researchers. These existing datasets are limited in their abilities to infer stand biomass and productivity. Crucial deficiencies stem from the employment of standard dendrochronological procedures for sample collection. Typical procedures involve the researcher specific decisions for how many trees (usually < 20), of which social status (usually dominant), in which area (usually undefined), and with what associated metadata (usually excluding key variables such as tree height and maybe even tree diameter). These procedures do not allow upscaling for stand biomass as i) the stand density is rarely quantified or able to be computed from the data collected, ii) possible biases related to collecting dominant individuals may be subtle in origin but profound in their consequences for inferred growth trends (Melvin 2004), iii) the number of trees sampled varies, and iv) the sampling area is only roughly defined. Furthermore, sampling strategies themselves are varied and may tend to focus on old aged or most climatically stressed stands in a region, biasing data collected for being representative for common forests.

Here, we present an adapted sampling scheme which is suitable for site level net primary productivity (NPP) estimates and spatial upscaling of the results. Site control is introduced by a fixed plot size and shape. Furthermore, suitable metadata for tree-ring based biomass estimates are collected. We tested this approach at five different flux-tower sites located in managed forests of varying species composition, climate and stand history. From tree-ring width (TRW) measurements, we computed tree-specific annual biomass increments and made NPP approximations for each particular stand. These data provide an ideal basis for future comparison with eddy-covariance and model based productivity estimates.

Site description

To test the applicability of our productivity oriented sampling scheme, we selected five eddy-covariance sites (Tab. 1) which provide various measurements related to the terrestrial carbon budget. All flux towers are located in managed forests with a homogeneous age distribution and any dead material has been removed. Flux data are stored in the CarboEurope and Carbo-Extreme project databases. Sites were chosen for data availability, long-term flux measurements, detailed records of management history, homogeneity in the species distribution and general accessibility. Furthermore, they are located in different parts of the European continent and thus cover a broad range of climatic conditions (Fig 1). A further crucial criterion for site selection was the representativeness of the flux-tower's source area for the entire forest stand, but this consideration is beyond the scope of this extended abstract.
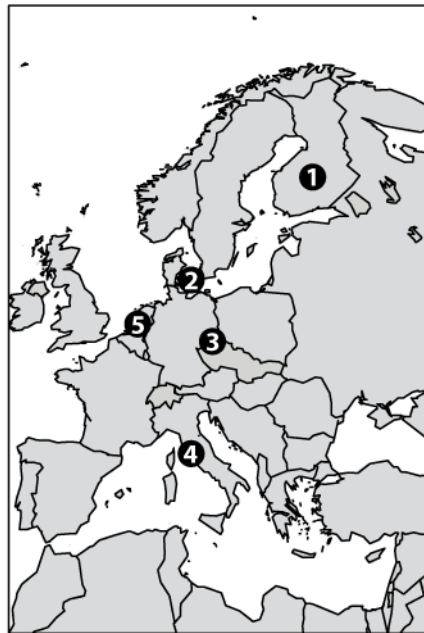
Figure 1: Geographic location of five flux-tower sites that were used to test the NPP-oriented sampling scheme. 1 – Hyytiälä (FIN), 2 – Soroe (DEN), 3 – Tharandt (GER), 4 – San Rossore (ITA), 5 – Braschaat (BEL)

Table 1: Site description

Site	Country	Elev [m a.s.l]	Species (%)	Plot radius [m]	Chronology	Av. Height [m]	Av. DBH [cm]
Hyytiälä	FIN	160	PISY (96) / BEPU(4)	10	1969-2009	16.7	13.2
Soroe	DEN	35	FASY (97) / FREX(3)	20	1925-2009	25.8	37.7
Tharandt	GER	360	PCAB (81) / LADE(19)	20	1899-2009	29.1	36.3
San Rossore	ITA	10	PIPI (13) / PIPN(87)	15	1952-2009	18.2	30.6
Braschaat	BEL	20	PISY(100)	22.5	1928-2009	19.0	30.9

Sampling

Scheme

Two circular plots were defined within the source area of the particular flux-tower (Fig 2). Plot sizes were adjusted according to stand density to include about 50 trees, which guarantees proper crossdating and robust chronologies. The radii at the five sites ranged from 10 m in Hyytiälä to

22.5 m in Braschaat. To include the relevant woody biomass, all trees within a plot were selected if their diameter at breast height (DBH) was greater than 5.6 cm. Each individual was marked, labelled and a minimum of two increment cores per tree was collected at breast height (1.3m). Samples were taken perpendicularly to each other to improve estimates for tree size and shape.
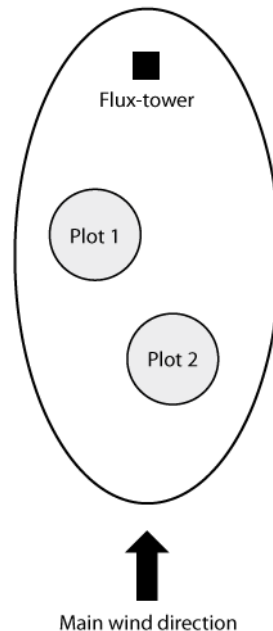
Figure 2: Schematic view of a sampling site. Sampling plots are defined within the footprint area of the flux-tower.

Equipment and Metadata

Since our study aims for stand NPP, some equipment for the necessary metadata acquisition was required. In case the increment cores did not reach the pith of a tree, the offsets were estimated according to standard dendrochronological practices (Schweingruber 1983).

The following metadata were collected for each tree within a plot (see Appendix A for metadata table) to ensure the applicability of species specific allometric biomass functions:

- Diameter at breast height (DBH, measurement tape)
- Tree height and crown base height (Vertex IV device)
- Social status (interpretation: dominant, co-dominant, dominated, suppressed)
- Tree location within the plot (Vertex IV for distance to plot center; azimuth measurement device)

Assessment of annual biomass production

Provided exact information on height and DBH of a tree, its total woody biomass can be estimated using species specific allometric functions. An overview of available equations (mainly above-ground) for different species, diameter ranges, competitive situations and tree components was compiled by Zianis et al. 2005. For our study, we selected suitable functions in terms of species, geographic proximity and competition. Where available, integrative equations providing full tree biomass were preferred to adding up biomass estimates from different tree components.

The following functions were used:

Hyytiälä: Mäkkelä & Vanninen 1998 (PISY)
Soroe: Wutzler et al. 2008 (FASY), Bunce 1968 (FREX)
Braschaat: Xiao et al. 2003 (PISY)
Tharandt: Pöppel et al. 1989 (PCAB), Gasparini et al. 2006 (LADE)
San Rossore: Baldini et al. 1989 (PIPI / PIPN)

Correctly dated tree-ring measurements allow for the calculation of historic tree diameters according to the variability in the TRW series. We used the method presented by Bakker 2005 to reconstruct annual DBH changes. Based on these, tree biomass was computed for each year using the respective allometric functions. In a next step, we derived annual changes in woody biomass for each individual and the entire plots. Assuming that all relevant biomass in a plot (of known size) has been included, we upscaled the annual biomass increment to the stand level NPP estimates.

Results

Annual increment and biomass estimates

Based on reconstructed tree dimensions, we calculated the annual biomass production of each tree at five sites in different climatic regions. At the site level, considerable differences in the growth rates were found between trees of similar age (Fig 3). In temperate regions, such as Soroe (DEN), Braschaat (BEL) or Tharandt (GER), tree biomass in 2009 ranged from below 50 to almost 1500 kg. At temperature (Hyytiälä) or drought (San Rossore) limited sites, growth was generally slower and the range of resulting 2009 tree biomass was clearly smaller (approximately 30 to 300 kg). In Soroe, Braschaat and Tharandt, the mean cumulative growth was stable or increasing whereas in Hyytiälä and San Rossore, annual growth rates started to level out towards the end of the chronology.
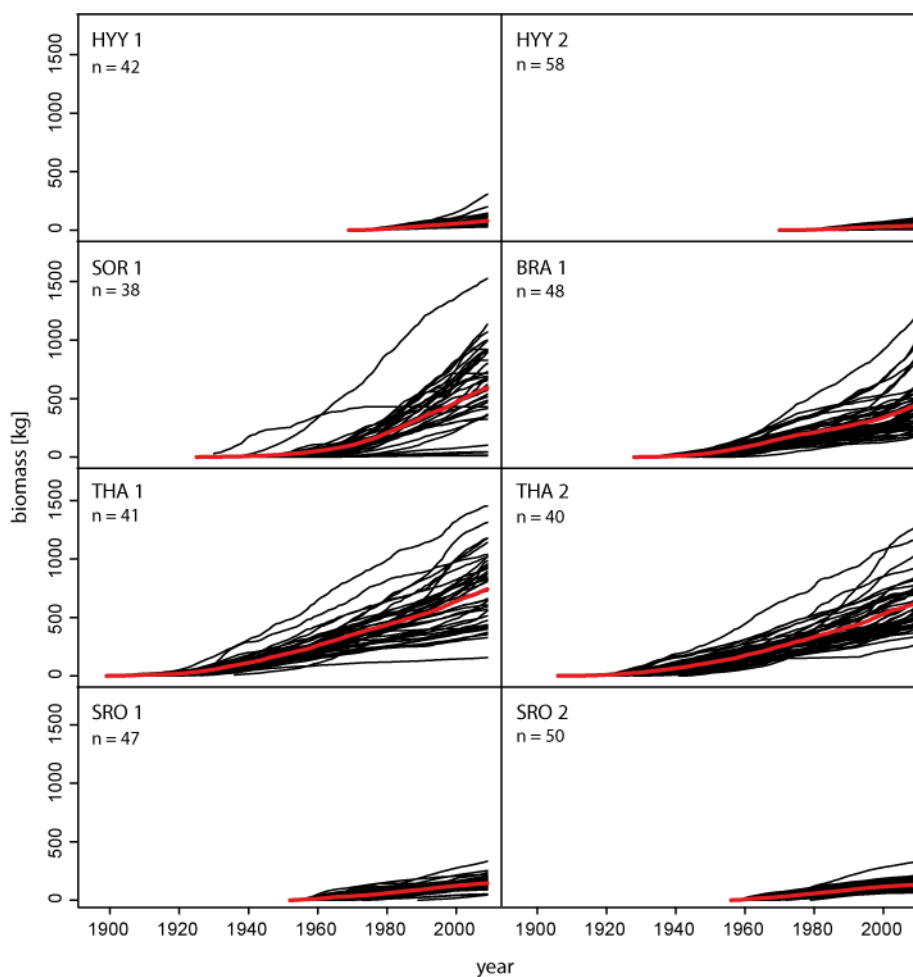
Figure 3: Cumulative annual biomass increment of trees at five sites. Number of individuals in each plot are indicated.

Upscale to landscape level

Stand level NPP estimates were made based on the sum of annual tree biomass increments and the plot area. Differences in the total productivity of the five forests were found to be much smaller than differences in the growth of individual trees (Fig 4). The low-frequency trends in the NPP chronologies differ greatly between sites. In Hyytiälä, productivity increased fast after plantation and leveled out after approximately 20 years. In Soroe on the other hand, NPP increased exponentially over 6 decades before starting to flatten. Braschaat shows a steady NPP enhancement during the first 40 years, followed by a depression of 2 decades and a repeated increase afterwards. NPP at the Tharandt site increased steadily for the entire 100 years after plantation. San Rossore increased productivity very fast in the earliest years followed by a relatively stable productivity level over 3 decades. After 1990, NPP started decreasing at this site.
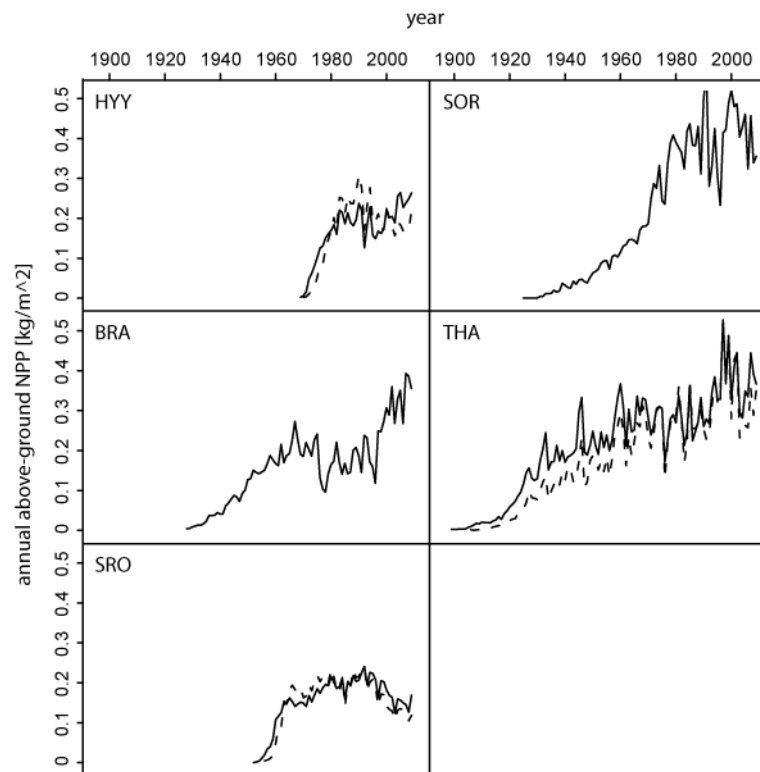
Figure 4: Upscaled annual above-ground NPP of five sites. Straight lines represent plot 1, dashed lines plot 2 (if available)

Discussion

We developed a new sampling scheme for dendrochronological studies, which allows for a more detailed site control compared to traditional approaches. Conventional studies often used tree-rings as a tool for long-term reconstructions (e.g. Trouet et al. 2009, Büntgen et al. 2011) and thus, fieldwork was primarily age-oriented. Old trees were sampled over an imprecisely defined area and only few metadata were collected at the site level. Consequently, existing tree-ring networks (e.g. Briffa et al. 2002, Wettstein et al. 2011) provide insufficient meta-information to estimate absolute forest productivity and thus, research questions related to the large-scale terrestrial carbon cycle cannot be properly investigated. Yet, there is need for empirical NPP measurements to validate and improve large-scale ecosystem productivity estimates from dynamic global vegetation models (e.g. Bellassen et al. 2011). Our adapted sampling scheme requires few additional equipment and if systematically applied, provides sufficient information to assess the scientific topics mentioned above. Furthermore, research related to within-stand competition (e.g. Kunstler et al. 2011) may benefit from the precise localization of trees in the predefined plots.

The absolute NPP values derived from allometric functions are potentially subject to uncertainty, since despite geographic proximity, site ecologies and tree shapes may slightly differ from the locations where the equations were developed (Zianis et al. 2005). Aditionally, existing biomass functions assume a constant wood density throughout a tree (e.g. Wutzler et al. 2008). Exact density will be measured at a later point and potential improvements and sensitivities of biomass estimates – which assume a constant wood density – will be tested. Furthermore, we reconstructed historic tree diameters and heights according to the variability in the tree-ring series. Thus, it was necessary to assume a linear relationship between primary and secondary growth as well as between wood and bark formation. These assumptions are not entirely realistic (Bouriaud et al. 2005) and may slightly bias the NPP estimates.

The proposed sampling design was tested at five flux-tower sites in managed forests with different climatic conditions. We detected considerable productivity differences between trees in a temperate climate and stands with a temperature or drought limitation. Yet, stand density partly compensates for lower growth rates leading to comparable site NPPs. Forest management is clearly influencing the low-frequency trends in the site productivity stressing the importance of adapted silvicultural practices (Garcia-Gonzalo et al. 2007). The reconstructions presented start from the present state of the forest and do not include information on past management practices (e.g. artificial thinning of a stand). Such information, however, are important to validate the reconstructed stand biomass and may be used to correct the level of absolute NPP estimates, if necessary.

Acknowledgements

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Appendix A: Metadata table

Site:			
Coordinates	Elevation a.s.l	Main species	Notes

Tree code	Species	Alive / dead	DBH [cm]	Height [m]	Crown base [m]	Distance from center [m]	Azimut from center [°]	Social status

Appendix A: Table for Metadata collection.

Abandoned Oak coppice on both sides of the Jura Mountains: dendroecological growth models highlighting woodland development and management in the past

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Introduction

As documented in numerous written sources, coppice, for oak particularly, was a common practice in historical times in Western Middle Europe (Corvol-Dessert 2002, Buridant 2004). The same assumptions can be derived from dendrotypology for earlier periods (Billamboz, 2010). Considering the high potential of dendroarchaeology to highlight relationships between human societies and woodland development, or consequences of socio-economic changes on the forest structure (Billamboz 2003, Bernard et al. 2007, Girardclos & Petit accepted), reference possibilities to related dendroecological studies are rather scarce and sometime divergent (Haneca et al. 2005, Copini et al. 2007, 2009). Therefore, tree-ring investigations of abandoned oak coppice have been recently undertaken on both sides of the Jura Mountains in order to assess the variability of radial growth as well as to gain a first insight into the stand structure and dynamics. First results are presented here from four plots representing different conditions of forest management based on coppicing. Within the scope of dendrotypology, analysis focuses on the following aspects: (1) comparison of age trend pattern and growth rate in the first years of regeneration between trees generated from stool and from acorns. (2) Influence of degree of competition and social status of the shoots: coefficient of slenderness, sapwood proportions. (3) Abrupt growth changes resulting from coppice rotations and further woodland practices.

Site location and woodland management

Plots 1, 2 and 4 are located in Eastern France, in the forests of Chantrans, a small village on the first French Jura plateau (47°03'N-6°11'E, 620 m asl., Fig.1). The soil type, inherited from Jurassic limestone, is brunisol where a brownish B horizon is identified, without any evidence of clay accumulation. The typical depth is 30 to 50 cm. Humus indicator of intense biological activity is an eutrophic mull. The tree species composition shows a mixture of oaks (*Quercus robur and Qu. petraea),* beech (*Fagus sylvatica*), hornbeam (*Carpinus betulus*) and ash (*Fraxinus excelsior*). Hornbeam is located at its highest level for the region. Woodland at that place takes two very different structures under forest management. Communal forests are large woods managed as coppices-with-standards during the 19th century and through the first quarter or even the first half of the 20th century. Under this type of management, the density of the dominant trees, the standards, remains low. The crowns are rarely in contact. The coppice is exploited in the understory, with stump shoots harvested at each rotation, and the future dominant trees chosen mainly from seed trees (Lanier *et al.*, 1994). Most of these forests are now designed to high-forest conversion with a very scarce participation of vegetative sprouting. The second case is more specific of the Chantrans region, forest still a large area but, under private property, shows a mosaic structure typical of sylvo-pastoral practices. In this integrated approach, the same owner or a more complicated group of owners and users can benefit of farming (grazing) and forest products. Forest management mostly based on coppicing interests a small unit and is more related to economic

activity or to the community needs than a planification. In consequence of socio-economic changes occurred around 1960, these actual Oak (*Quercus robur / petraea*) stands managed as coppice to provide firewood and bark for tanning are now developing past their usual rotation length.

Near Neuchâtel (Fig.1), plot 3 is part of a municipal forest on the lower Swiss slope of Jura (47°01'N-6°57'E, 690 m asl.). At the latitude of Besançon and Neuchâtel, climate of western and eastern slope of Jura is differenced by annual total of precipitation: 1100 mm at Besançon and 930 mm at Neuchâtel. Winter temperature are colder at Neuchâtel, the mean value of mean temperature for the period December to February is 1,3°C and 2,8°C at Besançon. Spring temperature for the period from March to May are going in them way: 8,8°C and 10°C, but summer are more similar: 17,5°C and 18,4°C for June to August. Finally the assumption can be made the vegetation season is shorter at Neuchâtel and the summer is more dry. The soil type, also inherited from Jurassic limestone, is a brunisol, but the situation of the plot in a slope increasing the drying sensitivity. The stand is dominated by Oaks (*Quercus petraea*) regularly harvested by coppicing for the needs of fuel in the past and is now designed to high forest conversion by a public administration.
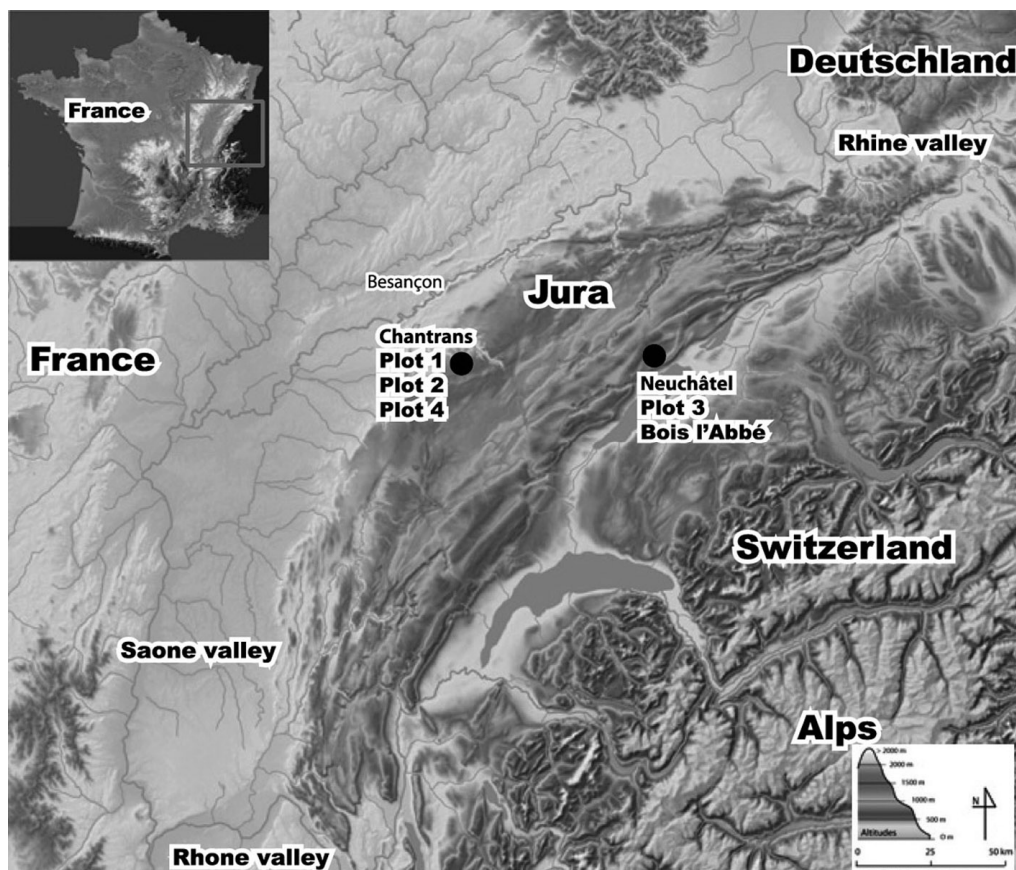

Figure 1: Map of the Jura mountains with location of the four investigated plots.

Material and methods

Table 1: Descriptive statistics. H moy: average total height with standard deviation between brackets, DBH moy: diameter at breast height, Age: age average in three generation classes deducted from measured and estimated rings of shoots, rm: mean correlation between shoot series.EPS:express population signal.

Site	Owner	H moy (m)	DBH moy (cm)	No of radii	No of shoot	Age 1st	Age 2nd	Age 3rd	rm	EPS
Chantrans plot 1	private	18 (1,5)	17 (3,5)	36	18	53	-	-	0,61	0,977
Chantrans plot 2	private	21 (2,1)	32 (4,2)	16	8	67	86	108	0,58	0,898
Bois l'abbé plot 3	public	-	34 (3,9)	16	8	162	193	-	0,48	0,981
Chantrans plot 4	private	19 (0,4)	22 (2,7)	14	7	63	81	-	0,52	0,978

According to the aspects of research mentioned above and related to the abandonment of coppicing the sampling method was not selective and retained first a large number of suppressed shoots. At Chantrans, diameter at breast height and total height are registered for each shoot sampled. Becker (1992) indicate the height/diameter ratio (H/D) or slenderness of oak tree depends on its average past competition status, firstly related to silvicultural treatment, and is independent of the site conditions. Nevertheless H/D ratio is also related to age. Young trees grow more preferentially in height than old ones. It is actually not possible to propose a model of the relation between slenderness and age in the case of oak coppice because of lacking sample depth. In consequence, for the presentation of these first results, the H/D ratio is interpreted taking into account age classes based on the coppice generations.

Samples take two forms, cores and cross sections if trees were cut by the owner. Coring has been made at 1 meter high, lower on the stem as usual in order to optimize the expression of the cambial age of relatively young and small trees (Tab. 1). To determine the age of shoot when core borer failed the pith, innermost missing rings are estimated using xylem rays convergence and the average width of the 5 first measured rings. This value is compared as appropriate to cross sections from the same plot, to age of sprout and diameter at breast height. Tree-ring widths were measured at least along two radii with a Lintab and TSAP device (Rinn 1989). The chronology development was performed using the Sylphe programme (Meignier, copyright GNU-GPL 2001). To assess the chronology construction for each plot, mean correlation and Express Population Signal (EPS) of "shoots series" have been computed, taking account of intra and between tree variability (Tab.1). Values are systematically above the level defined by Wigley et al. (1984), thus indicate that trees are dependant of common factors and chronologies are statistically relevant. Particular attention was paid to the evaluation of the sapwood proportions as indicator of social status and stand density. Finally cambial age trend is estimated by averaging raw ring width series age estimated aligned and growth trend in the plot chronology is exhibited by application of a Loess function (Cleveland, 1981) on raw data.

Results

Trees in plot 1 (Fig. 2) have been clear-cutted for tanning around 1958. Accordingly, the regenerated coppice stand is even-aged and all shoots have around 53 rings (Tab. 1). Consecutively to the abandonment of harvesting the stand has not be thinned since this date. Competition between shoots of the same or different stools has now a strong impact on growth reflected (1) in slenderness of the stem (Fig. 4) and (2) in strong negative age trend and narrow rings (Fig. 3). This is the fact of reduced conditions of light for suppressed trees (Roussel 1978). The H/D ratio is globally higher than in the other plot. Within the plot conditions and for the given

age class, order the series based on H/D ratio returns to judge the influence on shoot of competition. Dominated shoots show a slower duraminisation, a larger number of thin sapwood rings than dominant ones. In this situation, the Pearson coefficient of correlation between H/D ratio and sapwood number of rings reach the value of 0,45.

Figure 2: Pictures from the different plots.

In plot 2 (Fig. 2), stand management cannot really be distinguished between harvesting or regeneration cuts and thinning cuts. Logging conducted after owner's needs mainly based on fire wood supply. Accordingly, stand structure is still uneven-aged. Tree age spans three generations of shoots (Tab. 1). The oldest trees sampled regenerated near 1900. The second and third generations indicate cutting operations 22 to 25 years and ca. 50 years later. During the last 70 years harvesting has been more or less abandoned. Concerning the form of the coppice trees, two cases are observed: 1) all the shoots from a stool have the same age, which indicates the entire tree has been harvested at one time; 2) a selective cut concerned only one part of the shoots. In

consequences, the trees and shoots remaining in place benefited differently of the thinning measure. In comparison with other plots H/D ratio is lower but sampling doesn't permit a comparison at constant age (Fig. 4). Growth trends take different forms between generations (Fig. 3). The oldest trees started to grow with their largest rings. For the second generation first new rings are wide but growth reaches the highest rate 15 to 20 years later. Certain series show very narrows rings in first years indicating the shoot cannot break free of an intense constraint during a certain time. In this sylvo-pastoral context browsing is an assumption.

Plot 3 (Fig. 2), is an especially old coppice where some trees are 200 years old. Growth rate is globally lower than in other plots in relation to local and climate settings. Two main tree generations have been sampled. Their respective growth begin shows a lag of 30 years, here probably a rotation length between two cuts. Selective cuts are highlighted by repeated growth release of shoots. More generally, the growth rate of the oldest trees increased at the beginning of the second generation linking hereby the growth release to the thinning operations (Fig. 3).

The stand plot 4 consists of last relicts of an even-aged coppice in competition with oak seed trees and spontaneous silver fir (*Abies alba*) regeneration from plantations (Fig. 2). H/D ratio positioned in the high part of the points distribution whatever the age (Fig. 4), indicates seed trees are in relatively dense stand.
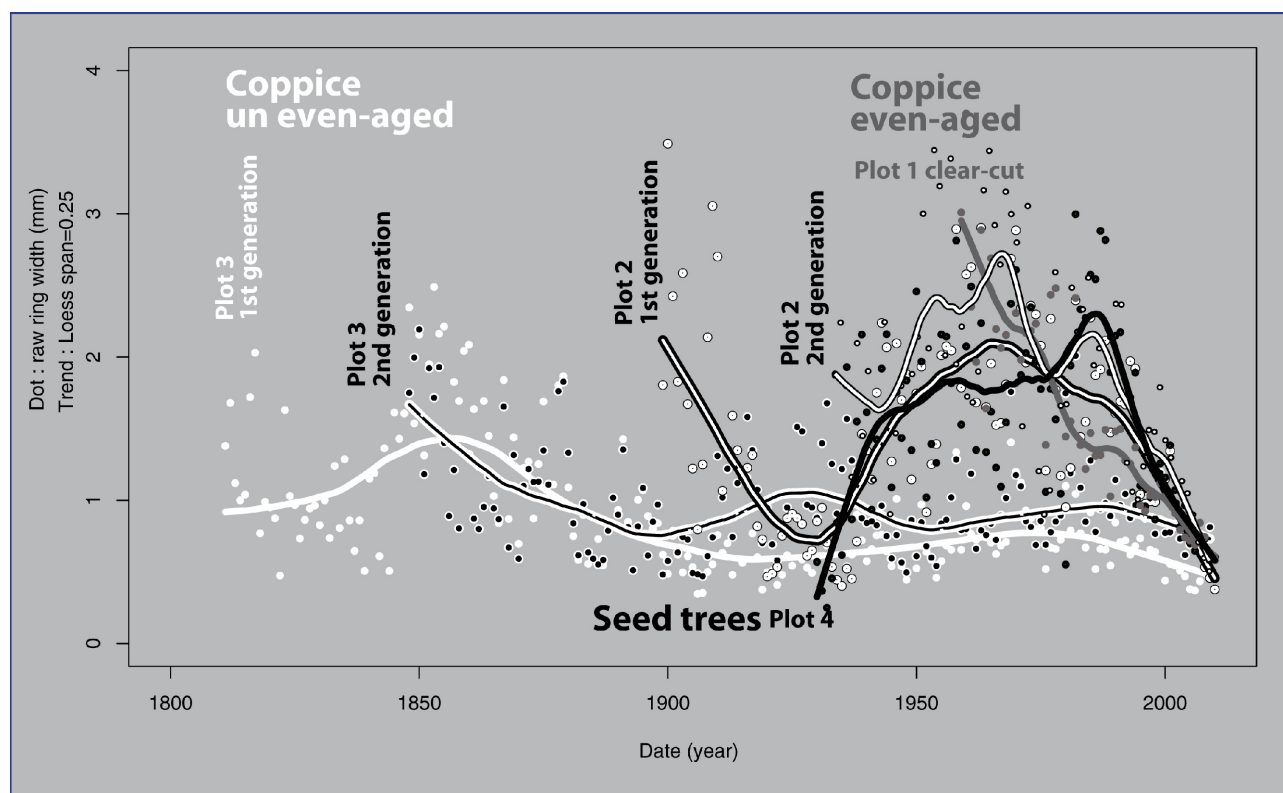

Figure 3: Selection of average chronologies computed for each plot generation of shoot. Dot showing raw average and solid line growth trend as define by a Loess function.
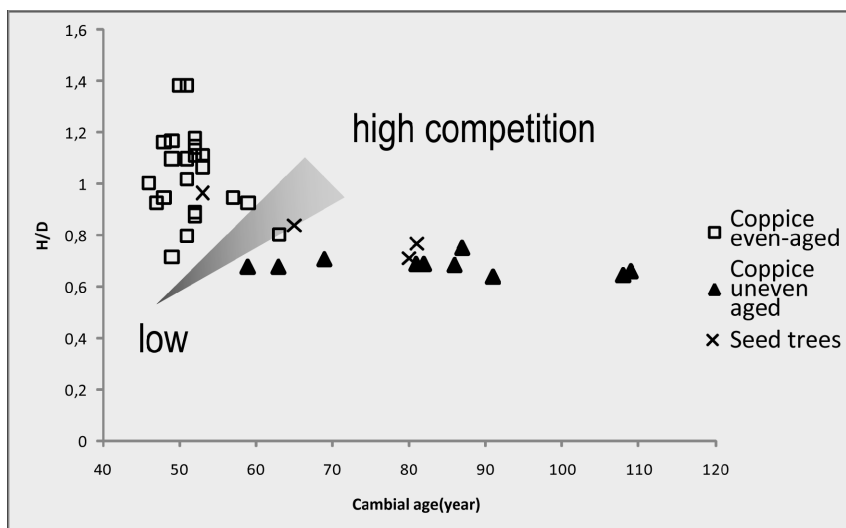
Figure 4: Relation between H/D ratio, slenderness, and cambial age.

Discussion

Field observations, information from the owners and age estimation permit to describe two types of coppice on the sites: 1), consecutively to a (local) clear-cut the coppice structure is even-aged, 2) consecutively to selective harvesting the coppice structure is uneven-aged.

Trend patterns

Trend patterns exhibited from raw mean chronologies are presented for each plot after classification of "shoot series" according age and competition status, in a similar way followed by the dendrotypology method used in dendroarchaeology (Fig. 3). This representation allows considering common information for a generation of shoots according to chronology and age trend. One can observe that most of the chronologies from coppiced stands are beginning with 5 to 15 wide rings. This is the more obvious for even-age coppice whatever the competition the shoots undergo. For uneven-aged coppice, the largest rings of the series are not systematically the youngest ones. Competition conditions are more complexes especially if the cut deals with the dominant shoots, sparing the weakest ones, or if browsing occurs. Sometimes, growth release is observed consecutively to selective cut, in individual series and for a generation in the stand. Comparatively, trees regenerated from acorn in the same site reach a maximum of growth rate after 15 to 20 years.

Age trends comparison

"Age-aligned" series collectively describe the functional form of the overall cambial age related growth trend typical for the species, on a given site or in a given region (Esper et al. 2003). Although, if aged-aligned series from large datasets are classified according silvicultural systems significant differences are observed between age trend patterns (Badeau 1995, Girardclos 1999). Here, trends observed in even-aged coppice under increasing competition rate are compared with large Eastern France datasets from stands managed as coppice-with-standards and from high forest where oaks selected are mostly regenerated from acorns (Fig. 5). In the case of coppice stand resulting from a clear-cut, shoots from stools analyzed show a growth rate above 3 mm during 3 years and surpassing the one given by other regional silvicultural systems during 5 years. General assumption to explain this fact is that shoot benefit of a fully developed root system. After no more than 10 years, growth rate decrease and can be explained by thinning intensity and competition grade as estimated by tree and stand parameters. But more complicated situations

resulting from selective cuts should invite to test the interactions between remaining root system and thinning benefits.
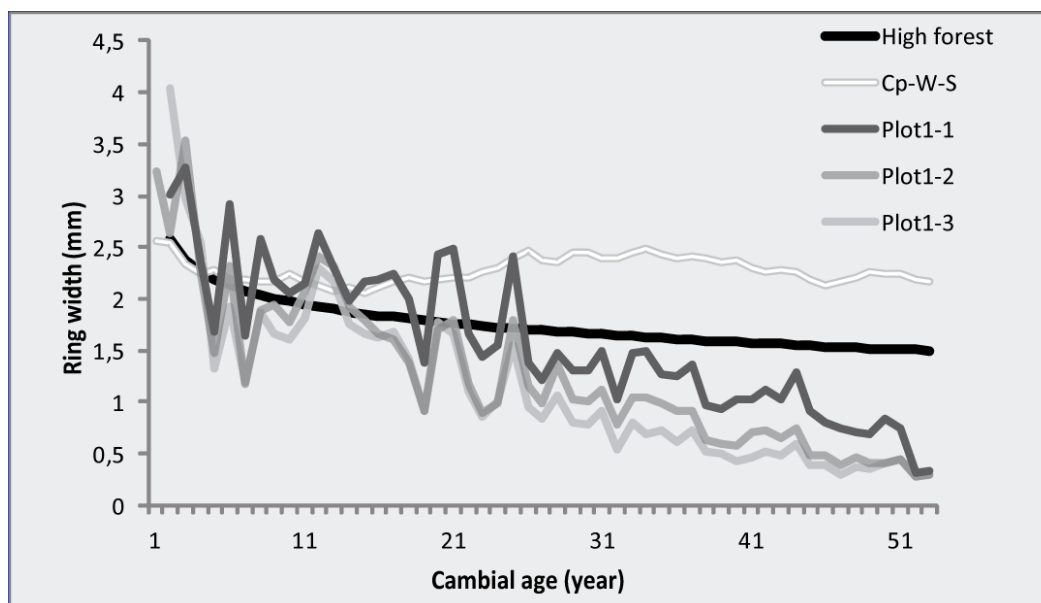

Figure 5: Comparison of cambial age trend computed for shoots of even-aged coppice at plot 1 and regional datasets. Plot1-1 to 3: data ordered in three classes according to the H/D ratio. Cp-W-S: average ring width of 298 trees from forests of French Jura where coppices-with-standards management is well documented (data from Chrono-environnement; Besancon). The curve for high forest is a model adjusted to the data of 505 trees from the forests of Amance and Champenoux (Meurthe et Moselle, France; Becker et al., 1994).

Conclusion

The sampling set allowed outlining some trend differences in ring width series related to coppice management. The first results we present show for the situation sampled (1) that shoots regenerated from stools have a higher growth rate than seed trees in the first 5 years of growth and (2) seed trees studied reach a maximum of productivity after a larger delay of time. However, before to use these observations as references for the past, it is important to raise the structure diversity of stands studied. Investigations of uneven-aged coppices suggest that competition "stories" can be variable even in the very first years of shoot regeneration. Along with the enlargment of this first data set, further work should be directed to the investigations of new plots submitted to other conditions of coppice management and rotations. The question of stand density and wood production will be also matter of study. However, the observations made here are in the spirit of dendrotypology. Conclusions on rate of initial growth, age trend and sapwood proportions are valuable for dendroarchaeological applications, dealing with the reconstruction of past silvicultural practices.

Acknowledgements

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Regional curve standardization of visually classified tree-ring features

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Introduction

Time-series of the relative frequency of visually classified tree-ring features are meanwhile an established method to estimate the climatic background of latewood density anomalies like e.g. intra-annual density fluctuations (IADFs). IADFs are a direct reaction of trees to specific patterns of environmental conditions (e.g. Wimmer et al. 2000). In the Mediterranean region, drought stress in summer can initialize cell-wall thickening and trigger the formation of terminal cell rows. Precipitation following such a drought phase with cambial dormancy can reactivate cell formation and thus lead to the formaton of an IADF (e.g. Campelo et al. 2007). The relative frequency of other distinct ring-types such as narrow, missing, or light rings can also be used as indicator of specific environmental conditions.

Since the first analyses of the relative frequency of visually classified tree-ring features, there have been discussions about the effects of age-trends inherent in frequency time-series. Some studies observed a decrease of IADFs towards cambially older rings (Bräuning 1999, Wimmer et al. 2000, Copenheaver et al. 2006). To address this problem, one possible solution is the use of age-classes in order to assess the age-dependency of the frequency (Vieira et al. 2009). A second method selects relatively old-grown trees to minimize age-related effects (Wimmer et al. 2000, Vieira et al. 2010). However, none of these methods can effectively remove age-related artefacts in time-series of relative frequencies.

In ring-width studies, cubic smoothing splines are often applied to each single series to remove age-trends and non-climatic disturbances (Cook 1981). However, long-term climatic signals are likely to be removed from the resulting standardized index series. Hence, regional curve standardization (RCS) is increasingly applied to retain low frequency signals and to effectively remove age-related biases (for a review see Esper et al. 2003, Briffa & Melvin 2011). In contrast to ring-width series, splining of single IADF curves is not possible due to the binary nature of the IADFs. Applying spline-detrending to curves of a relative frequency will result in a loss of any trend in the signal.

Another important issue in ring-width analysis is the quality assessment of chronologies. Different parameters were developed to assess the signal strength or the confidence of a chronology, such as the mean correlation between all series forming a chronology ($\bar{r}$ or $rbar$) (Briffa & Jones 1990) and the expressed population signal (EPS; Wigley et al. 1984). EPS estimates how well the signal of the sample collection reflects a theoretical chronology which consists of an infinite number of samples. EPS uses the mean sample number of a given interval and the mean (Pearson's) correlation between the samples for a maximum common overlap period:

$$EPS \approx \frac{N\bar{r}}{1 + (N-1)\bar{r}} \quad (1)$$

Admittedly, series of visually classified tree-ring features are not normal distributed. Therefore, the calculation of Pearson's correlation coefficient of binary variables is mathematically not correct.

Variance stabilization methods have been applied since the beginning of the investigation of frequency-chronologies (e.g. Rigling et al. 2001). The procedure applied is the multiplication of the frequency with the square root of the number of all samples in a given year y, where $f(y)$ is the number of samples showing an IADF $k(y)$ divided by the total sample number $n(y)$:

$$F_{stabilized}(y) = f(y) \cdot \sqrt{n(y)} = \frac{k(y)}{n(y)} \cdot \sqrt{n(y)} \quad (2)$$

Our objectives are (1) to present a classification to capture intra-annual but also year by year variability of density, (2) to suggest and discuss a method to assess signal strength of visually classified tree-rings and (3) to remove possible biases resulting from the age-dependency of classified features and unstable variance. For illustration we applied our techniques to a dataset derived from Corsican pine tree-rings (*Pinus nigra* spp. *laricio*).

Material

We visually classified tree-ring features in 8702 rings from 96 samples of *Pinus nigra* using a numerical classification code (Tab. 1). Increment cores were collected during two field-trips in 2008 and 2010. The cores were air-dried, cross-sections were cut with razor-blades and chalked to optimize contrast between cell-lumen and cell-walls. If necessary, resin was removed from the surface by ethanol or acetone. Ring-width measurements were performed with a LINTAB 5 linear table (Rinntech, Heidelberg, Germany) to the nearest 0.01mm.

Methods

Classification

Each annual ring was visually examined under a microscope and a characterization for each ring was tabulated. Rings were classified as "1" if light or less dense latewood appeared and as "2" for dark or dense latewood. We also considered the width of the latewood by using a second digit. Thus, broader light latewood was coded as "11" and variable density with a transition from dense latewood to broad light latewood as "211". A maximum number of 3 digits was used for latewood characterization (one digit for narrow, two digits for normal-width, three for broad). An additional digit position (1XXX) was prefixed for density fluctuations occurring within earlywood. If a sharp tree-ring demarcation was visible and additional less dense latewood was found, we added a decimal place (e.g. XX.1). This ring-classification has also been named as "A" (Leuschner & Schweingruber 1997) or as "L+" (e.g. Campelo et al. 2007) in other publications. We used the code of each ring classification and the already established E+ (instead of 1XXX) and L+ (XXXX.1) codes to describe our results (for examples see Fig. 1, the full classification table is given in Tab.1).
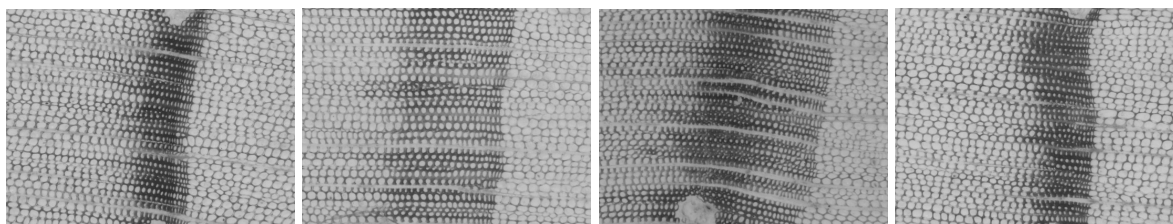

Figure 1: Examples of L+, 11, 211 and 12 rings.

We verified the accuracy of our visual classification by checking the number of classified rings with previously performed ring-width measurements of total ring width, earlywood width and latewood width. Furthermore, patterns of frequent ring types were recognized and used for cross-dating. The

resulting data matrix of all classified rings was filtered to retain binary data matrices for each separate ring classification type. By this method, we created a large dataset that enabled us to investigate signal strength, the effects of variance stabilization and age-detrending on visually classified tree-ring features.

Table 1: Classification code for visually distinguished density variations. Light gray represents light latewood, dark gray dense latewood. The number of digit positions reflects the width of latewood.

EW	IADF EW	EW	LW	LW	LW	LW+		class
	0		0	0	1	0	=	1
	0		0	0	2	0	=	2
	0		0	1	1	0	=	11
	0		0	1	2	0	=	12
	0		0	2	1	0	=	21
	0		0	2	2	0	=	22
	0		1	1	1	0	=	111
	0		2	1	1	0	=	211
	0		1	2	1	0	=	121
	0		1	1	2	0	=	112
	0		1	2	2	0	=	122
	0		2	2	1	0	=	221
	0		2	1	2	0	=	212
	0		2	2	2	0	=	222
	1		0/1/2	0/1/2	1/2	0	=	E+ or 1XXX
	0/1/2		0/1/2	0/1/2	1/2	1	=	L+ or XXXX.1

Signal strength assessment

The derivation of (1) is based on the approximation of the subsample correlations by *rbar* (Wigley et al. 1984). However, $\bar{r}$ is, as mentioned before, only appropriate for normal distributed variables. Correlation of two binary variables can be done by the φ-correlation coefficient (r_φ) (e.g. Bortz et al. 2008). The numerical value of r_φ is identical with the Pearson's product moment correlation coefficient. Thus, programmed routines of $\bar{r}$ and EPS are feasible to calculate a measure of signal confidence. Mathematically correct, *rbar* must be replaced by *rbar$_\varphi$*.

Frequency stabilization

Without considering any corrections, the frequency of a classified ring-type is just calculated as

$$f(y) = \frac{k(y)}{n(y)} \quad (3),$$

where the sum of *k(y)* is the number of samples in a given year showing a specific feature, divided by the number of all samples in a given year *y*. Osborn et al. (1997) originally proposed the use of the following formula to account additionally for the common mean correlation to get an effective sample number:

$$n_{eff}(y) = \frac{n(y)}{1 + (n(y) - 1) \cdot \bar{r}_\varphi(y)} \quad (4)$$

Mean correlations in IADF-datasets are normally low which makes the approximation of *rbar$_\varphi$* ≈ 0 acceptable. However, in some cases (e.g. in our Corsican pine data set) *rbar$_\varphi$* is considerably different from zero and should therefore be taken into account in variance correction. For the

computation of the stabilized frequency the square root of the effective sample number is multiplied with the raw frequency. Scaling can be done by division by the square root of the maximum sample number (5):

$$F_{stabilized} = F(y) = \frac{k(y)}{n(y)} \cdot \sqrt{\frac{n_{eff}(y)}{N}} \qquad (5)$$

Detrending

Regional curve standardization (RCS) is the most promising concept to remove age-related biases in frequency based series. In ring-widths studies, the mean of all series, which are aligned to their cambial age, is calculated. A spline curve is fitted to the mean curve to compute a smoothed age-trend curve (regional curve). Each individual series is then divided by this regional spline curve. Applied to datasets of visually classified tree-ring features, series were also aligned to their cambial age ($k(y) \Rightarrow k(a)$); rearrangement was accomplished using a modified version of the dplR-package function "rcs", Bunn 2008). To account for the increasing variance due to the decreasing sample number with increasing age, we used again variance stabilization (6),(7), with *m(a)* as the sample number at a given cambial age a, $rbar_\varphi(a)$ the mean correlation of each cambial aligned series and M the maximum number of samples at a given age a:

$$m_{eff}(a) = \frac{m(a)}{1 + (m(a) - 1) \cdot \bar{r}_\varphi(a)} \qquad (6)$$

$$K(a) = k(a)\sqrt{\frac{m_{eff}(a)}{M}} \qquad (7)$$

Originally, the data-structure of visually classified tree-ring features consists of a binary data matrix. After transformation, detrending and scaling, effectively each occurrence of a specific ring-type is weighted according to the calculated age-dependent frequency. Thus, the values are not binary anymore, but range from 0.0 to 1.0. The maximum value of 1.0 is only retained for a stable variance and if age-related effects are negligible.

To remove age-related effects, we divided the raw age-dependent count number of specific rings by an age-trend curve derived from a best-fit curve (*C(a)*), a cubic smoothing spline with a length of 96 years and 50% frequency cut-off (8). Division by the age-trend curve retains the zero-values for years without any occurrence. The resulting number is scaled by the maximum value after detrending (9):

$$\hat{K}(a) = \kappa \frac{K(a)}{C(a)} \qquad (8)$$

$$1/\kappa = \max\left(\frac{K(a)}{C(a)}\right) \qquad (9)$$

The detrended series can now be rearranged to their chronological distribution and the stabilized frequency can be calculated (10):

$$F_{2x\ stabilized}^{detrended}(y) = \hat{F}(y) = \frac{\hat{K}(y)}{n(y)} \cdot \sqrt{\frac{n_{eff}(y)}{N}} \qquad (10)$$

The resulting frequency chronology is free of variance and age-related biases. The effect of each single step of the procedure is shown in the following examples. No deviation from the original curve means that the sample number is stable and that no age-related biases are inherent in the data.

Results & Discussion

Signal strength assessment

The EPS-values of Corsican pine ring-type chronologies of above 0.85 indicate that the sample number is suitable for the evaluation of climatic signals triggering density variations (Fig. 2). It is noteworthy that the number of correlations is often below the possible maximum number according to the sample size since several series consist exclusively of zero-values. Thus, no correlations can be computed with these series.
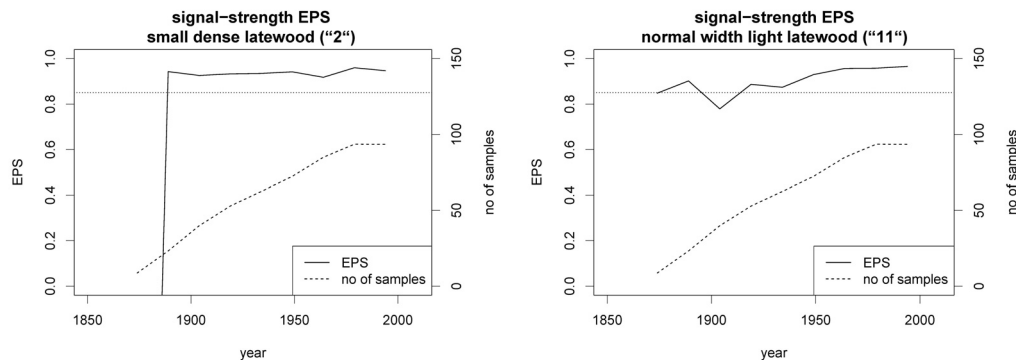

Figure 2: Running EPS-values (window-length 30 years, overlap 15 years) and sample number for two ring types of Corsican pine.

Another important point is that our datasets often produce negative or insignificant correlation values, if too few or no ring features are found. However, in some cases the correlations to climate parameters are impressively high, even in case of low EPS values. In the case of simultaneously weakly correlated single series, the mean interseries correlation will not give an adequate estimate of the real signal strength. We therefore suggest a lower EPS threshold value of 0.75 for a still acceptable frequency chronology. This is also relevant for vessel-parameter chronologies, which often lack high EPS-values due to low replication, but are highly correlated to climate parameters (e.g. Fonti & García-González, 2008). Otherwise, alternative parameters for assessing the signal strength of frequency chronologies have to be developed.

Detrending

Detrending of visually classified frequency time-series becomes necessary, if the frequency is highly dependent on the cambial age of the sample. The different spline curves in Fig. 3, namely the raw, the variance stabilized, the age-detrended and the variance stabilized age-detrended frequency curve, illustrate the diverging trend behaviour of the detrended and original series. In the case of tree-ring feature "12" (Fig. 3), nearly a third of all samples showed the transition from light latewood to dark latewood during young cambial age. Variance stabilization also accounts for some significant biases. The frequency of ring-type "2" (Fig. 4) with an expected and observed increase in frequency in cambially older rings also shows high age-related effects. The raw data are characterized by a steep trend over the last years of the chronology. After detrending, only a moderate long-term increase is observed. However, some ring-types show nearly no age-trend. "L+"- events in Corsican pine trees (Fig. 5) are distributed nearly independent of tree age. In such cases, differences to raw value series are marginal.

Copenheaver et al. (2006) also found an age-related decrease in the relative frequency of false rings which might have obscured underlying climatic triggers. In their study, no relationship between false rings and climate was found. Possibly, the use of spearman's rank order correlation coefficient and detrending is a more suitable technique for detecting climatic triggers for false ring formation. The selection of only old-grown trees like in the studies of Wimmer et al. (2000) and

Vieira et al. (2010) is only a suitable approach, if enough old-aged samples are available. Although data-inherent age-trends can be statistically removed from a relative frequency-chronology, age-dependent differences in climate responses can still be present and have to be considered when analysing climatic triggers causing different tree-ring types (Vieira et al. 2009).
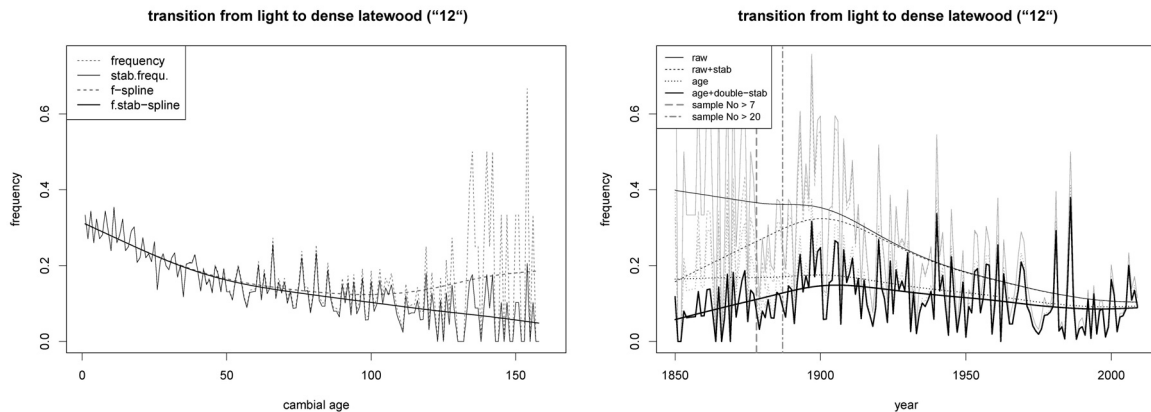

Figure 3: Relative frequency of the transition from less dense to dense latewood. In Fig. 3a (left figure), all series are aligned to cambial age, in Fig. 3b (right figure) they are arranged chronologically. Frequency of "12" shows a strong decrease towards cambially older rings. Thus, inherent trends in the raw chronology are eliminated after detrending.
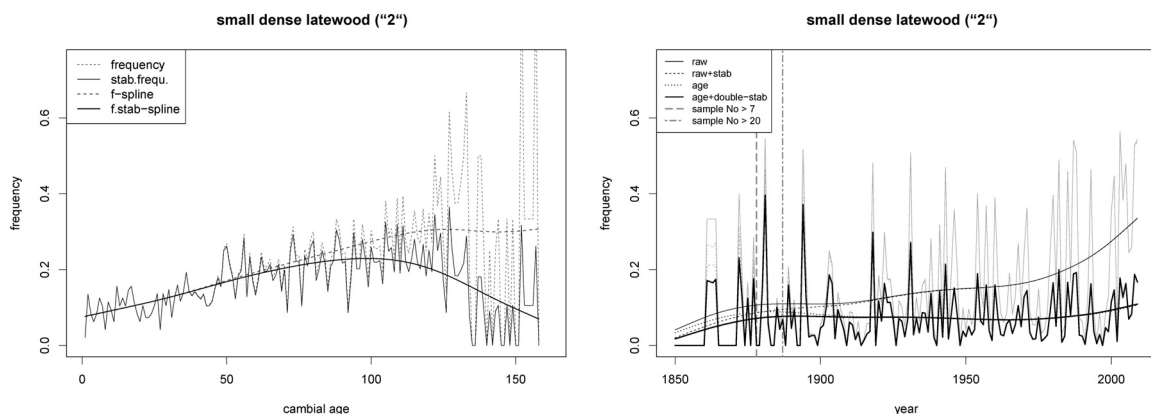

Figure 4: Relative frequency of small dense latewood, which decreases to cambially older rings. A strong trend towards the end of the chronology was mitigated. In Fig. 4a, all series are aligned to cambial age, in Fig. 4b they are arranged chronologically.
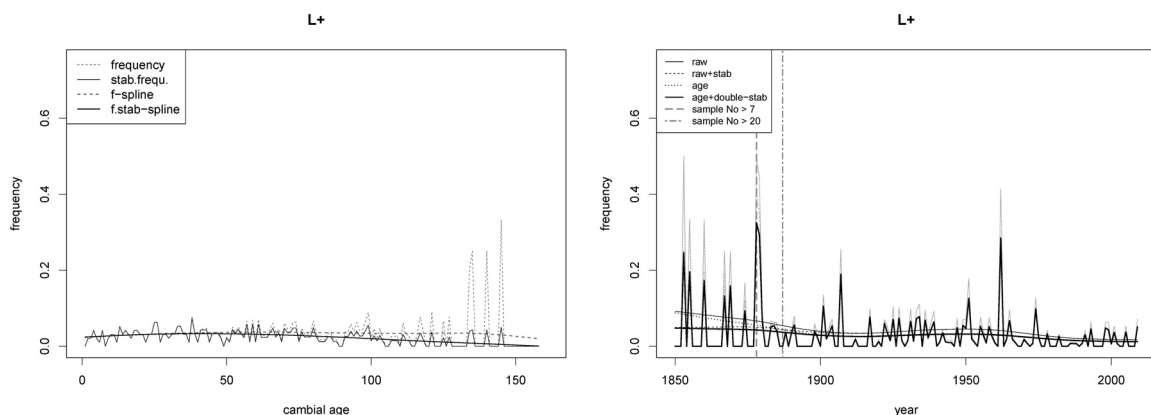

Figure 5: The relative frequency of "L+" is characterized by a continuation of latewood after a sharp tree-ring demarcation. Almost no age-dependent trends occur. Therefore, frequency stabilization accounts for some changes only in the early part of the chronology.

Conclusions

Our approach intends to stimulate the discussion about data quality and appropriate data-processing of visually classified tree-ring features. Visual classification has the potential to complement ring-width based climate reconstructions and is suitable to detect extreme climatic events of the past. The most important advantage of this procedure is that past climate variations can be assessed without the usage of cost-intensive X-ray or high-frequency densitometry equipment. The easy method to capture tree-ring features and the automated data-processing are fast and reproducable. For establishing robust relative frequency chronologies, we recommend a high number of samples (20-50) and a balanced age-distribution to avoid possible biases.

Acknowledgements

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Using tree growth suppression as an indicator of infant mortality caused by air pollution (Upper Silesian Industrial District, Poland)

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Introduction

The emission of pollutants into the atmosphere has clearly had adverse effects on both human and tree health. A simultaneous increase in mortality and disease rates was recorded in many areas of the world where forests were destroyed due to the atmospheric emissions of pollutants; the Chernobyl industrial disaster being an extreme example of this. The studies on influence of air pollution to tree growth suppression were conducted near different sources of pollution (Ashby and Fritts 1972; Vinš and Mrkva 1973). Reduction of radial tree growth depends mainly on distance of trees from the pollution source and the amount of pollution emitted into the atmosphere (Thompson 1981; Kennedy-Sutherland and Martin 1990; Nöjd et al. 1996; Junkys et al. 2003; Elling et al. 2009). New method of studies on ring reduction caused by air pollution was applied by Schweingruber et al. (1985) and was based on the analysis of pointer years and abrupt growth release.

Atmospheric pollution also leads to an increase in disease and mortality rates among infants. The epidemiological evidences suggest that adverse health effects depend both on the concentrations and duration of exposure (Cohen et al., 2005). Negative association between air pollution and birth weight was shown by Bell et al., (2007) and Gray et al., (2010). A relationship exists between maternal exposure to air pollution during periods of pregnancy and low birth weight. Wang et al. (1997) suggest that ambient pollution increase is associated with this effect in Beijing. Studies have shown that air pollution may increase the risk of adverse birth outcomes, for example the risk of premature birth (Maroziene and Grazuleviciene, 2002). Studies carried out in Japan confirmed that adverse human health effects can be compared to the occurrence of ring reductions (Kagamimori et al., 1990).

The general intensification of tree growth suppression was observed near the Upper Silesian Industrial District (USID), southern Poland between 1960 and 1990 (Danek, 2007). Study of the concentration of airborne pollutants in the USID has proved the influence of these pollutants on the daily mortality pattern of the inhabitants (Kowalska et al., 2010). Absalon and Ślesak (2010) suggest the existence of a relationship between cadmium-lead air pollution and cancer among children in the USID.

The aim of the study was: (1) to show relationship between variability of air pollution recorded in tree ring reductions and infant mortality in USID, (2) to assess the possibility of using tree ring reductions as an indicator of future adverse effects on human health.

Material and Methods

The study was carried out in southern Poland, in the Silesian Upland, about 5-20 km north of the USID, in the Silesian Voivodeship, where heavy industry operated without any environmental protection until 1990. Many coal mines, steelworks and other factories were closed due to their unprofitability after 1990. Standards of environment protection were established and applied to industrial plants. This often led to a decrease in production. Data related to coal exploitation, steel and energy production were chosen to illustrate the post-war industrial growth in the USID because of the lack of air pollution data for the USID during years of communism. These data had the

longest available time-sequences and the highest completeness (Statistical Yearbooks, 1958-2009; Fig. 1A).
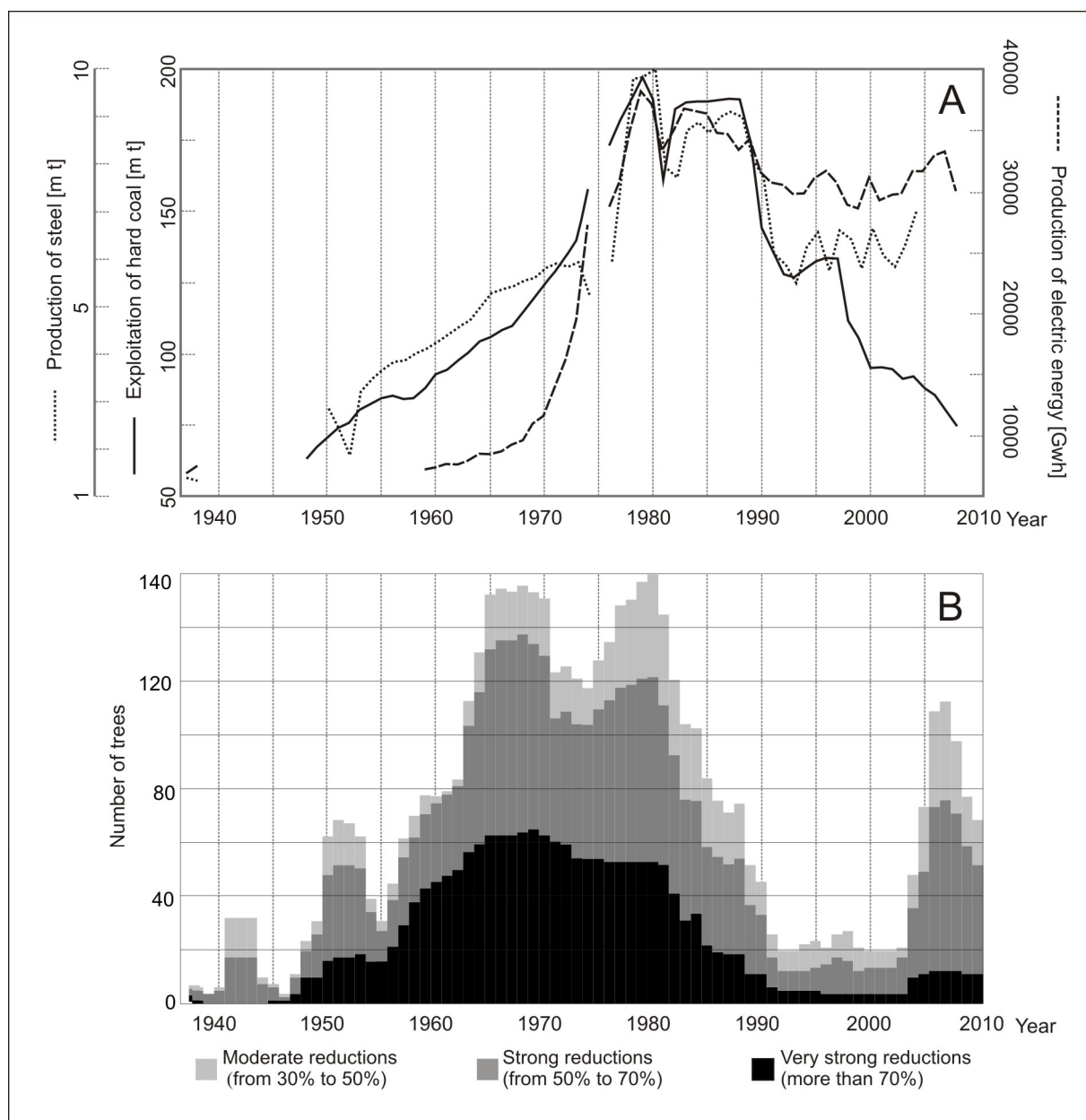

Figure 1: Comparison of coal exploitation, steel and electrical energy production in the USID with tree ring reductions; A – production of steel, electric energy and exploitation of hard coal; B – number of pines sampled showing ring reductions.

200 cores were taken in November 2009. Samples were obtained using the Pressler borer, from 90 years old pines (*Pinus sylvestris* L.) growing 5-15 km north from USID at 11 sampling sites. Twenty trees were sampled at each site. Cores from twenty trees were also collected at one reference site located about 60 km northwest of the USID, relatively far from the harmful emission sources. Afterwards the annual ring widths were measured and tree ring series from all pines were fitted visually and correlated using TREE-RINGS (Krawczyk, Krąpiec 1995) and Quercus software (Walanus, 2002). Based on the individual tree ring curves site chronologies and local, standardised chronology were developed in ARSTAN. For every sapmple tree ring reduction periods were determined and their values were calculated as the total tree ring width of all rings in a reduction period in relation to the total tree ring width of all the same number of rings from the period

preceding the reduction period (Schweingruber et. al., 1985). Calculated reductions were classified into three groups: moderate reductions: 30-50%, strong reductions: 51-70%, very strong reductions: >70%. The Quercus software was used to determine reduction periods and calculate their values (Walanus, 2002).

Epidemiological data were collected from the Statistical Bulletins of the Ministry of Health (1966-2009). To find a possible correlation between tree ring reductions and infant mortality the medical data were detrended and lagged by 1, 2, 3... up to 14 years. The detrending procedure was necessary because strong temporal trends, related to the development in medical care, occur in the data set. Detrending allowed to eliminate influence of factors identical for the whole Poland (for instance: tobacco smoking, UV-B radiation, etc.) from the results and interpretation.

The index (detrended) rates were obtained by subtracting avg. infant mortality for the whole Poland from infant mortality in the Upper Silesia (year by year). This relative parameter – infant mortality index – was used in further analyses. All correlations were lagged to test if tree ring reductions can be used as a kind of predictive instrument for the future health-related consequences of increasing pollution.
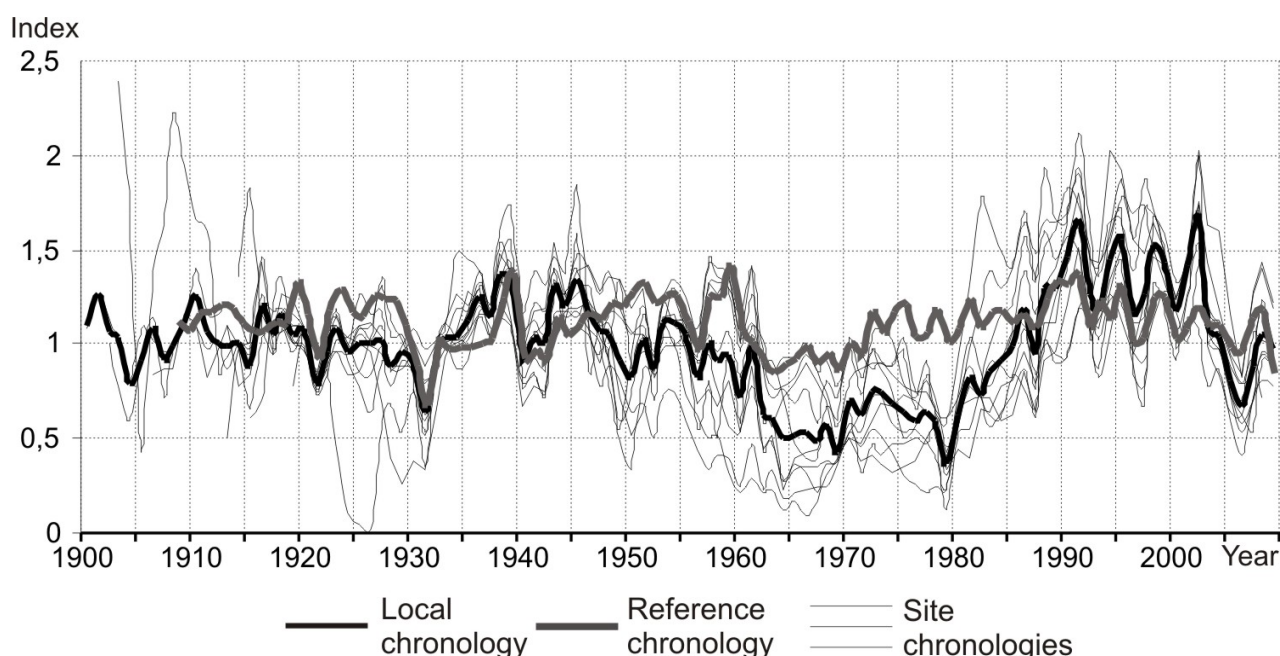

Figure 2: Standardized reference, local and site chronologies developed from tree-ring series from sampled pines.

Results and Discussion

Pines growing at study sites which comprised the local chronology generally produced narrow rings between 1960 and 1985 (Fig. 2). At the same time the trees, which the reference chronology was composed of, formed relatively wider annual rings. In the sampled pines ring reductions were recorded between 1950 and 1990, and from 2003 to till now (Fig. 1B).
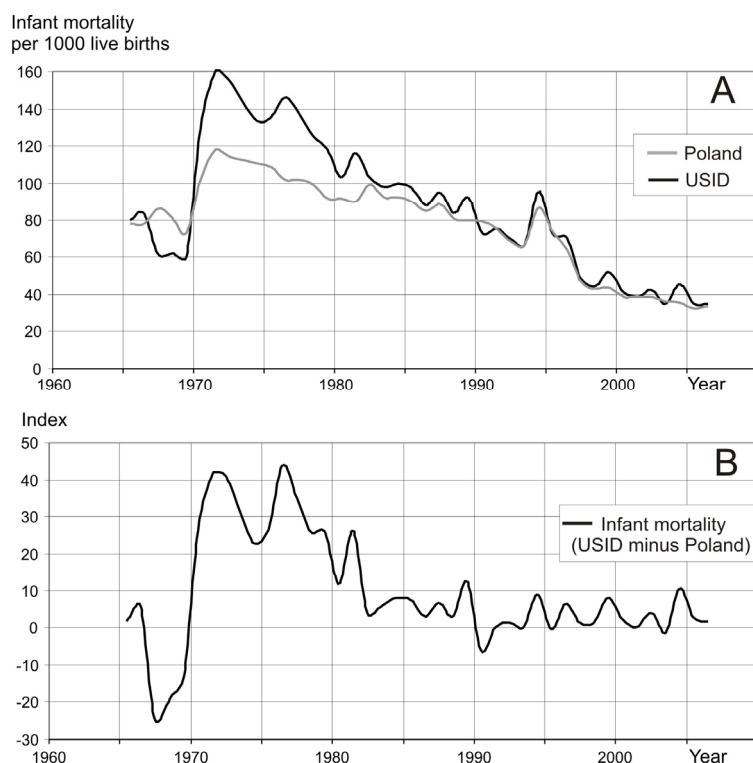
Figure 3: Relationship between infant mortality rates in Poland and the Upper Silesian Industrial District, A – variability of infant mortality rates in the USID and in Poland, B – infant mortality index (USID minus Poland).

The highest number of tree ring reductions occurred from 1964 to 1981. A clear inverse ratio can be observed between the increase of coal exploitation, steel and electrical energy production and the number of ring reductions (Fig. 1). This means that, in all probability, air pollution suppressed pine growth near the USID.
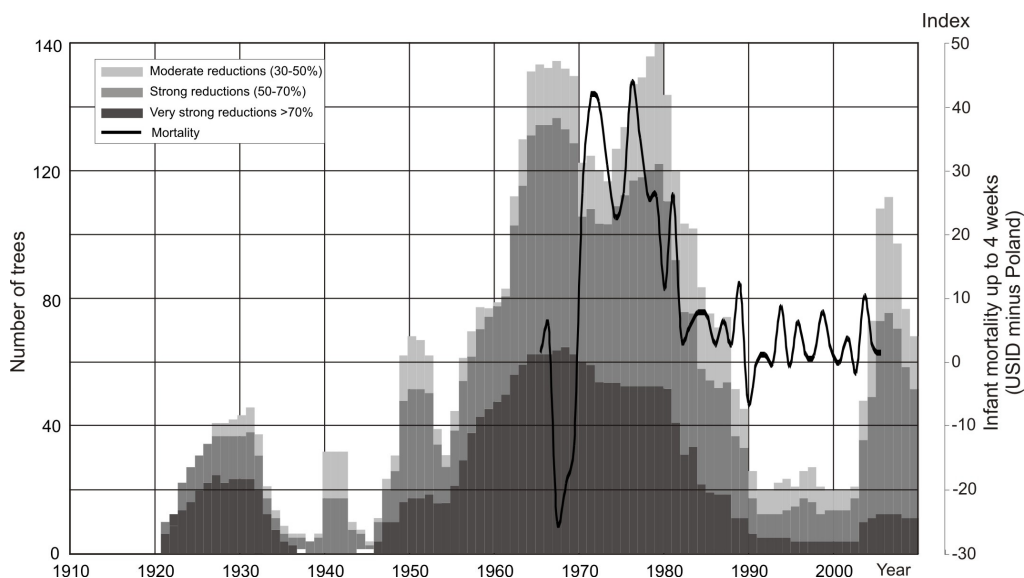

Figure 4: Relationship between the number of trees with reductions and infant mortality rates.

Between 1970 and 1981 the infant mortality rate for new born babies up to 4 weeks old in the Upper Silesian Industrial District was significantly higher than in the rest of Poland (Fig. 3). The high amount of tree ring reductions in sampled pines affected by air pollution correlate with periods of high infant mortality rates in the district (Fig. 4).

The increase in the number of tree ring reductions occurred earlier than the increase in infant mortality rates (Fig 4). It means that the reaction of the trees to air pollution occurs before the infant mortality increase, because pines react more immediately and may have lower threshold values for pollutant content in the air. The calculation of the correlation between infant mortality and tree ring reduction shows the highest value of correlation (from 0.42 to 0.45) when infant mortality is lagged by 6-8 years (Fig. 5).
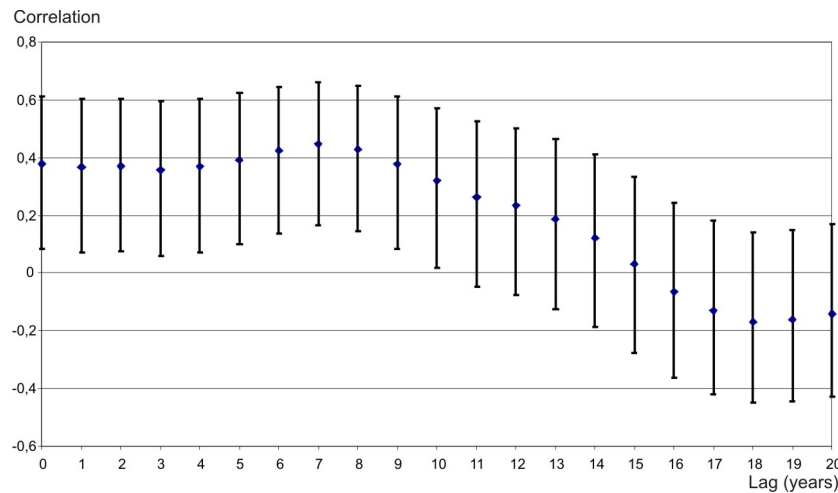

Figure 5: Correlation and confidence intervals for total tree ring reductions and lagged rates of the index of infant mortality (detrended).

Conclusions

1. Deep ring reductions in pines growing north from USID occurred earlier than the increase in infant mortality rates. The high correlation values over a span of 6-8 years are due to the culmination of years of high air pollution emissions.

2. It may be possible to create the basis for a model, which could be developed and used as a tool to forecast the adverse effects of air pollution on human health. The model should be based on the measurements of ring reductions in selected tree species which are recognised to be the best indicators of air pollution. The correlation model presented is very simple and makes many assumptions (such as the constant lag between the reaction in trees and people over time). The creation of reliable forecasting model needs further studies.

3. The opportunity to create a biological network that would provide advance warning about health hazards seems to be significant for developing countries (e.g. India, China, Brasil, etc.), where the local economy mainly relies upon conventional sources of energy (coal, wood and gas) and where the automatic stations for monitoring air pollution control are not widely used for various reasons.

4. If applied to developed countries, the model may support instrumental monitoring systems (networks of measurement stations), providing information about the combined effects of pollutants and allowing to forecast health consequences in populations exposed to air pollution. A health risk forecasting model would take into account the relationship between tree reaction and the occurrence of negative health symptoms among humans.

Acknowledgments

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Reactions and recovery times of *Fagus sylvatica* after drought events derived from of ring width and maximum latewood density

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Introduction

According to the projections of the IPCC-scenario A1B, summer temperatures in southern Germany will increase up to 2.4°C until the end of this century. Even more important, a remarkable change in the seasonal distribution of precipitation is expected with an increase in winter precipitation and a decrease in summer rainfall. Summers are predicted to be warmer and drier while there will be a surplus of water in spring-time. Besides, extreme climate events in central Europe are expected to be more intense and more frequent. Thus, forests will most probably suffer from increasing and more frequent summer drought stress (Christensen et al. 2007 [IPCC], Rennenberg et al. 2004, Sutmöller et al. 2008). It is still uncertain how forests and individual tree species will react to these climatic changes and their consequences, but higher drought stress will probably influence the vitality, the stability and the productivity of European forests. As a result, forest management strategies as well as the choice of cultivated tree species have to be reconsidered and adjusted (Sutmöller et al. 2008).

We study the growth reactions of common beech (*Fagus sylvatica*) and sessile oak (*Quercus petraea* (Mattuschka) Liebl.) to severe drought events. Climatic extreme events are often imprinted in tree rings as abrupt growth reductions which also influence tree growth of the years following a climatic extreme event (Schweingruber 2001). In the light of the expected increasing intensity and frequency of drought events in the future, it is important to know if beech and oak will still be able to grow on edaphically dry sites or if the recurrence interval between drought events will be too short for these species to recover. Our approach is therefore to determine the recreation time of beech and oak to recover from severe drought events during the 20th century. The final goal is to estimate if these tree species are already potentially endangered at dry sites or if they are able to cope with more frequent and intense drought events.

Different wood parameters show diverse reactions and sensitivities to climatic variables (Skomarkova et al. 2006). Thus, we investigate a combination of the wood parameters ring width (RW), maximum latewood density (MXD), wood anatomical parameters and stable carbon isotopes. Here we focus on the reactions of ring width and MXD of *Fagus sylvatica*, which is one of the economically most important tree species in central Europe, to selected drought events.

Material and methods

We investigate a spatial network of 7 chronologies of *Quercus petraea* and 8 chronologies of *Fagus sylvatica* on climatically and edaphically dry sites in northern Bavaria, situated at elevations from approximately 300-580 m a.s.l.. Mean annual precipitation within the study area ranges from 600 mm to 900 mm, while mean annual temperature is between 7.6 °C and 9.1 °C (Lasermann & Bräuning 2011).

Two cores from each of 15 dominant trees were sampled at breast height from beech and oak at each study site. Ring width was measured with a LINTAB linear table (Rinn, Heidelberg, Germany) and TSAP-Win software (version 0.53, Rinn 2003) was used to synchronise the ring width curves visually and statistically. Maximum latewood density measurements were carried out by using high-frequency densitometry only for *Fagus sylvatica* at three study sites (Tab. 1) (LIGNOSTATION,

version 2.20c, Rinn 2003, Schinker et al. 2003). Considering the high variability of the wood density measurements of the single trees we tried to obtain a common signal by the number of samples.

Table 1: Statistics of ring width- and maximum latewood density-chronologies and characteristics of sampled trees (RW: ring width, MS: mean sensitivity, AC: autocorrelation (lag=1), DBH: diameter at breast height)

Study site	Species	Chronology statistics							Sampled trees characteristics	
		Chronology	Length of series	Mean RW / mean density	MS [%]	AC 1	rbar	First year EPS > 0.85	Mean tree age	Mean DBH [cm]
Ebrach	*Fagus sylvatica*	RW	155	200	19	0.62	0.505	1910	139.6	63.3
	Fagus sylvatica	MXD	148	20075	5	0.37	0.078	---		
Geisfeld	*Fagus sylvatica*	RW	161	157	23	0.49	0.448	1900	147.7	49,8
(Ottobrunnen)	*Fagus sylvatica*	MXD	146	19747	7	0.25	0.271	1945		
Hiltpoltstein	*Fagus sylvatica*	RW	157	181	17	0.80	0.506	1910	134.5	60.4
	Fagus sylvatica	MXD	151	20360	5	0.20	0.169	---		

* Mean RW [1/100mm], mean density [As/Vm *10^{-4}]

Ring width measurements and MXD measurements were standardized in ARSTAN (version 41d, Cook 1985) using a cubic smoothing spline filter which removed 50% of the variance of frequencies at two thirds of the series length. Ring width indices were calculated by dividing ring width by the spline values while residuals were calculated by subtraction for MXD series (Schweingruber 1988).

To analyse the growth climate-response, linear correlations were computed between monthly mean temperatures and monthly precipitation sums for a period from April of the previous year to October of the current year and the indices of ring width and MXD, respectively (Fig.2). The calculations were computed with the program DENDROCLIM2002 (Biondi & Waikul 2004), using the bootstrapping to calculate correlation coefficients.

To analyze the effects of drought on ring width and MXD, we applied Superposed Epoch Analysis (SEA). With this method it is possible to quantify the average reaction before, during and after extreme climatic events. We calculated the SEA regarding the last eight most severe drought years of the last century in the study area. These selected drought years were defined as years in which the annual precipitation sum departs more than one standard deviation from the long-term mean (Lasermann & Bräuning 2011). For computation of the SEA we used the programming language R (www.r-project.org/ version2.10.0), and the package dplR (dendrochronology program library in R; Bunn 2008).

Results

The Gleichläufigkeit (sign-test) between chronologies from ring width and MXD chronologies of common beech is 51% (insignificant, 1862-2009) at Ebrach, 58% (p<0.05, 1864-2009) at Geisfeld Ottobrunnen and 58% (p<0.05, 1859-2009) at Hiltpoltstein. Despite the low average correspondence of both wood parameters, they often show a synchronous decline in the selected drought years (Fig. 1).
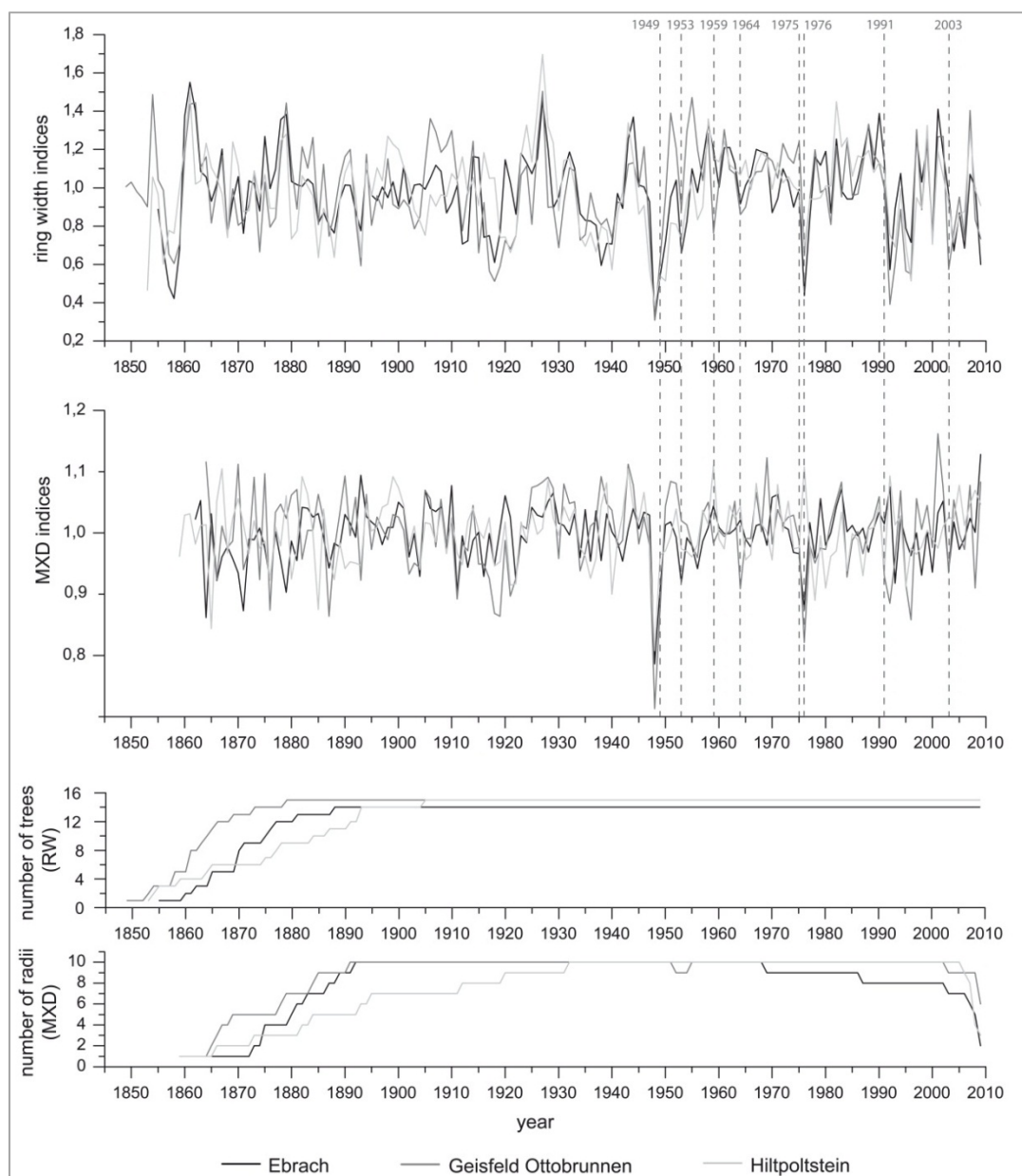
Figure 1: Standardized ring width chronologies and MXD chronologies of Fagus sylvatica from three study sites. Dashed lines indicate the last eight most severe drought events.

Correlation analysis revealed that ring width and MXD of *Fagus sylvatica* are influenced by different climate parameters. Correlations coefficients are exemplarily presented for site Ebrach (Fig. 2). However, it should be noted that the results show also differing climate-growth relations at the three study sites. At all sites previous year's temperatures in July and August are distinctly negatively correlated with ring width, while precipitation and temperature of the previous year's October show positive correlation values. Another common signal is that ring width is positively correlated with current year's precipitation in June and negatively with temperature from April to July of the current year. Regarding the climate-growth correlations of MXD, the pattern is less clear. At all study sites precipitation in July of the current year is negatively correlated with MXD, while temperatures in July and August show high positive correlation values. At Ebrach and Geisfeld Ottobrunnen, MXD is positively correlated with previous year's October temperature and with precipitation from February to June; however the latter time period is negatively correlated at Hiltpoltstein.
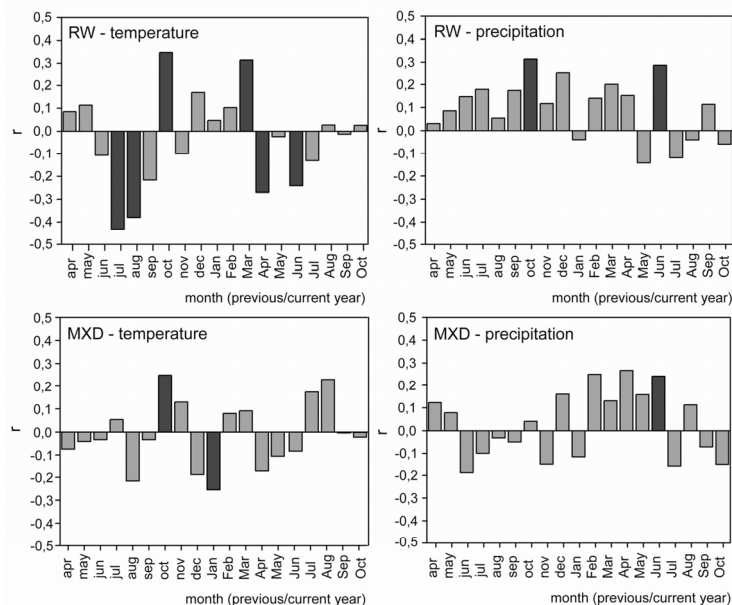
Figure 2: Correlations of ring width (RW) and maximum latewood density (MXD) of Fagus sylvatica with temperature and precipitation (1964-2009), respectively, at study site Ebrach (dark grey indicates values significant at p<0.05)

The SEA of the extreme drought years (Fig.3) reveals a different behaviour of ring width and MXD: *Fagus sylvatica* shows a distinct reduction of ring width in the event year (0) and the following year (1). The normal growth level is not regained before the second year after the drought (2). MXD instead shows a marked decrease in the event year (0), but seems to recover faster from drought. At site Ebrach, MXD recovered in the first year (1) after a drought event, whereas at site Geisfeld Ottobrunnen, MXD showed a slower recovery, comparable to that of ring width.
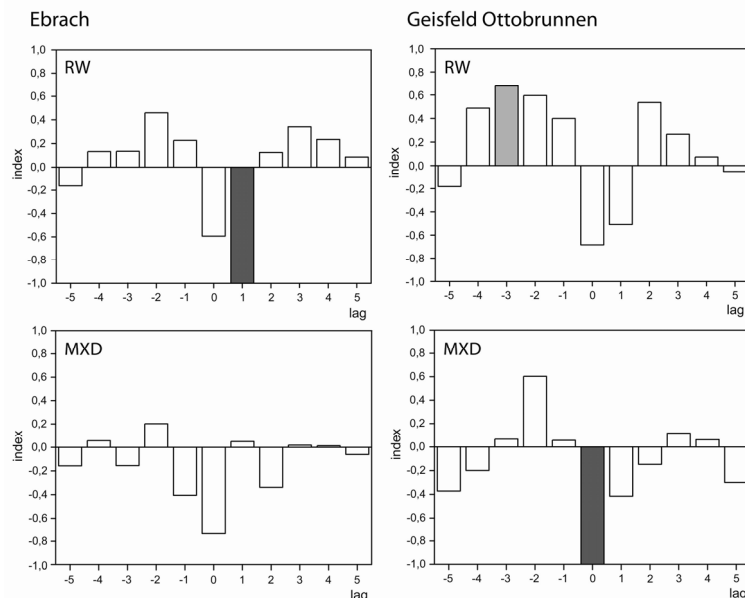

Figure 3: Superposed Epoch Analysis of the eight selected drought years (1949, 1953, 1959, 1964, 1975, 1976, 1991, 2003) of ring width (RW) and maximum latewood density (MXD) of Fagus sylvatica at the study sites Ebrach and Geisfeld Ottobrunnen. The diagram represents the average growth reactions in the event years (0) in comparison to growth in the five years before (-1 to -5) and following the event (1 to 5). The index value 0 corresponds to the normal growth level. Dark grey indicates values significant at p<0.01, light grey at p<0.05.

Discussion and conclusions

The potential of beech to adapt to climate change is recently discussed controversially (e.g. Rennenberg et al. 2004, Ammer et al. 2005, Kölling et al. 2005, Bolte 2005, Manthey et al. 2007, Sutmöller et al. 2008). Some authors are concerned that *Fagus sylvatica* might get harmed by the expected more Mediterranean-like climate conditions in Central Europe with increasing summer drought stress, at least at its current moisture-limited distribution boundaries (Manthey et al. 2007). However, these presumptions are not commonly supported. Besides the capability of elastic responses (like for example growth reductions), beech exhibits a high genetic variability, so there might also be the chance of evolutionary adaptation to the changing environmental conditions (Konnert et al. 2000, Bolte 2005, Kölling et al. 2005). Thus, suggestions to import foreign beech provenances from the Mediterranean region to Central Europe (Rennenberg et al. 2004) are regarded as problematic (Ammer et al. 2005). Since *Fagus sylvatica* does not tolerate extended drought periods (Muck et al. 2009), much will depend on the extent to which the frequency and intensity of drought events will increase in the near future. The knowledge about the duration of recovery times might help estimating if beech will be able to cope with future climatic changes, especially on edaphically dry sites.

Our preliminary results indicate different reactions and recovery times of the wood parameters ring width and MXD to severe drought events. Lasermann & Bräuning (2011) presented a comparison of a SEA for *Fagus sylvatica* and *Quercus petraea* from our study region. In contrast to oaks, beeches reacted with a significant growth decrease in ring width in the drought year and/or the following year. The normal growth level was not attained until the second year after the extreme event. Thus, for ring width a recovery time of two years was found.

In our first results of the MXD-analysis a decrease in MXD values during severe drought years was observed. The recovery phase for MXD seems to be accomplished faster than for ring width. Further analyses will show whether these preliminary results are spatially representative and whether they can be used to estimate the future prospects of *Fagus sylvatica* at edaphically dry sites in Central Europe.

Acknowledgments

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Which factors control tree growth in a tropical mountain forest? The case of *Cedrela montana* in Southern Ecuador

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Introduction

During recent years dendroecological and dendroclimatological studies of tropical tree species attracted increasing scientific interest. Updating a review article by Worbes (2002), Rozendaal and Zuidema (2011) recently provided a very broad overview over the latest developments on dendroecological research on tropical forests. Considering the dramatic loss of forest areas in tropical regions – especially in Ecuador with an annual forest loss rate of -1,8% (FAO 2011) and an ensuing decline of economically valuable timber species – it is obvious that dendroecological studies need to be continued and silvicultural concepts have to be developed to counter this non-sustainable trend. In addition to anthropogenic induced changes in tropical ecosystems, climatic extreme events such as droughts also determine tree growth reactions (Volland-Voigt et al. 2010, 2011).

Our study, firstly, sheds light on the linkage between tree growth rates and seasonal climatic conditions and, secondly, investigates the impact of silvicultural treatments minimizing competition effects on tree growth. We examined *Cedrela montana* (Meliaceae) which is a slow growing deciduous broad–leaved tree species with a height of up to 30m and a main occurrence in the tropical mountain rainforests of southern Ecuador (Nieto & Rodriguez 2003). This tree species is highly suitable for dendroecological studies forming a parenchyma band at the beginning of each growing season. Thus, this parenchyma band can be used to define annual growth boundaries (Bräuning et al. 2009). Furthermore, the wood of *C. montana* is characterized by a high durability and hardness causing a high economic value of the species (Smith 1960). Thus, knowledge about the effects of silvicultural treatments fostering the growth of valuable indigenous species are particularly useful for forest management.

Material and Methods

Study site

The research area "Reserva Biológica San Francisco (RBSF)" is located at the northern slope of the Podocarpus National Park (3°58'S, 79°04'W) with a total site area of about 11.2 km² and an altitudinal gradient from 1800m up to 3160m a.s.l. (Beck et al. 2008). Due to its location at the eastern range of the southern Ecuadorian Andes, humid air masses from the Amazon lowlands flow in the study region. Thus, the total area belongs to the tropical humid ecozone (Bendix et al. 2008a) where at 2100m (altitude of the study plots) the annual mean temperature is 15,5°C and the annual mean rainfall is about 2176mm (Bendix et al. 2008a, 2008b). Moreover, the average annual water intake by fog is approx. 120mm (Emck 2007). This site is characterized by shifts in seasonal rainfall amounts. While a wetter period is predominant from April to June, there is nearly no rainfall in the dry season from October to December in addition to strongly increased solar irradiation and a higher vapour pressure deficit (Bendix et al. 2008b).

Methodological approach

The methodological approach includes investigations on climatic–growth relationships and competition-growth relationships of *C. montana*. Since April 2006, stem diameter variations of four *C. montana* trees were measured at 30 min. intervals with high-resolution point dendrometers (Ecomatik, Germany). Rates of the daily radial changes can be calculated by the difference of maximum stem diameters of two consecutive days (Bräuning et al. 2009). To find out how this tree species reacts to long and short term climate variations, cumulative daily radial stem variations were compared to climatic data such as daily sum of precipitation and daily maximum vapour pressure deficit (mVPD).

Evaluating the competition-growth relationship, 38 individuals of *C. montana* were examined in two catchment areas. In 2004, an 'Improvement Felling' (felling of the strongest competitor) was carried out in a natural forest management experiment in the RBSF. The strongest competitor of each of 20 potential crop trees (PCTs) was felled to achieve a positive influence on the annual growth of the PCTs. The remaining 18 trees (reference trees) of the total 38 served as a comparative group, since no fellings were exercised. The trees were classified according to the Dawkins-Classification (Fig.1) which reflects the exposure to light for each tree scored on a scale from 5 to 1 (Dawkins 1958). In order to measure these effects on tree growth, the radial mean width before (1976-2003) and after the treatment (2005), were analysed by tree cores (Ø 5mm).
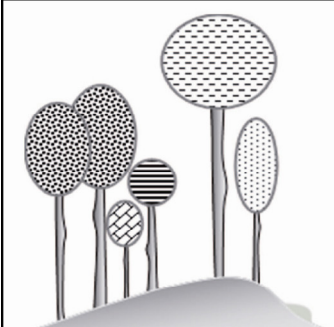

	HATCHING	SCORE DEFINITION
	5	Entirely exposed, free from competition of light **(Emergent)**.
	4	Exposed in entire vertical plan but in contact with other crowns laterally **(Upper Canopy)**.
	3	Partly exposed and partly shaded vertically by other crowns **(Lower Canopy)**.
	2	Entirely shaded vertically but with some direct side light **(Upper Underdstorey)**.
	1	Entirely shaded vertically and laterally by other crowns **(Lower Understorey)**.

Figure 1: Dawkins Classification (modified after Dawkins 1958)

Results

Seasonal growth dynamics and climate-growth relationship

Figure 2 illustrates the cumulative radial stem diameter variations and its connection with daily sums of precipitation and daily mVPD from April 2006 until the end of April 2010. Cumulative growth curves of the four studied trees are very homogeneous. The long-term trend of the dendrometer curves shows a seasonality of cambial activity between January to April, as indicated by a sharp increase in radial diameters. From the beginning of May until October, growth rates decrease in a conspicuous manner and only minor stem diameter variations are observed. This phase mainly coincides with the leafless period of *C. montana*, but also overlaps with the period when *C. montana* have leaves (Bräuning et al. 2009).
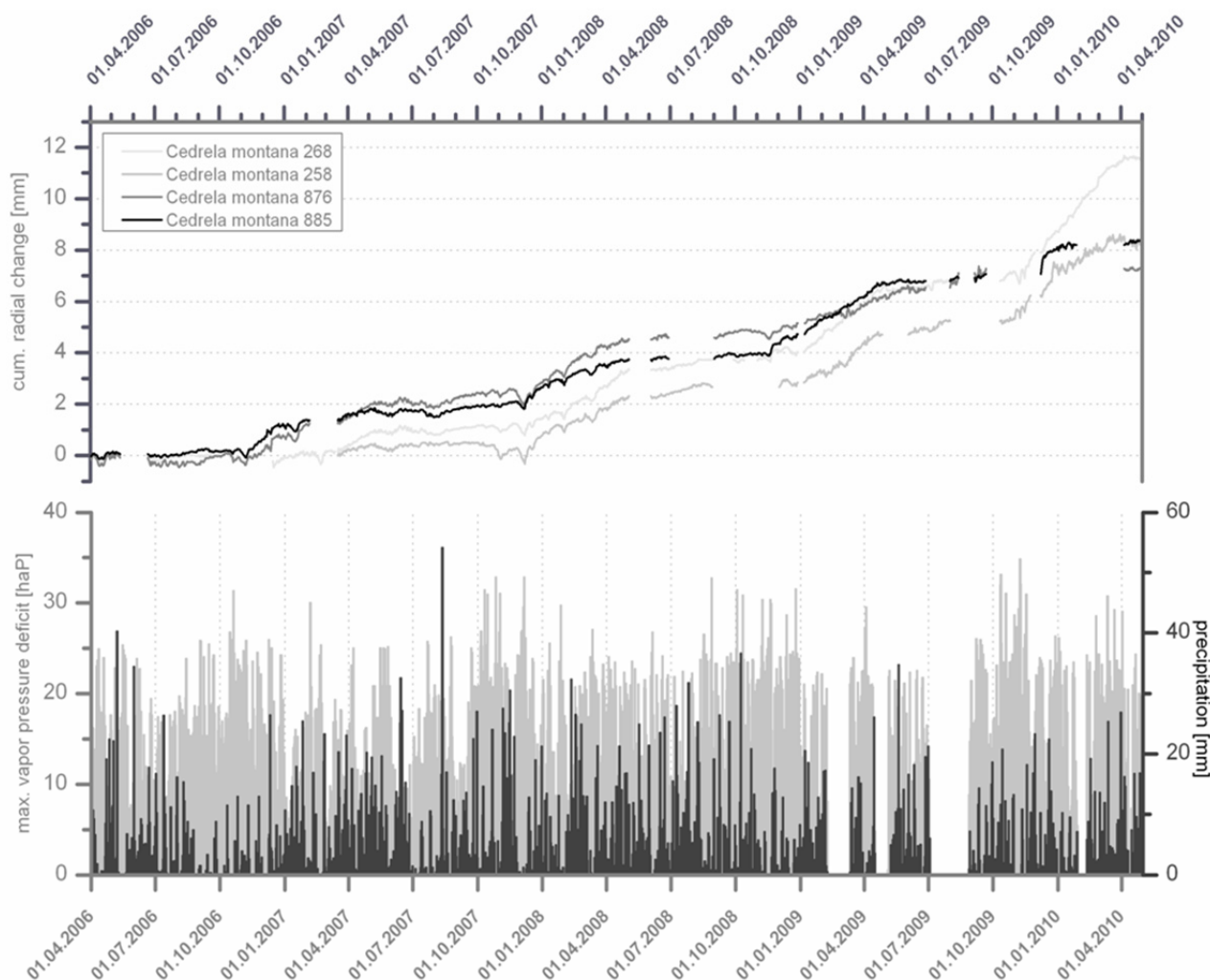
Figure 2: Cumulative daily radial stem variations (upper panel) of four C. montana individuals and climatic conditions (lower panel) represented by daily precipitation sums (black bars) and maximum vapour pressure deficit (grey bars; lower panel) during April 2006 to May 2010. Gaps in the individual growth curves are caused by data logger failures.

Beside this general growth trend, the four dendrometer curves also reveal synchronized short-term variations which are characterised by a drastic radial stem shrinkage during rainless periods (more than 13 days without rain). Figure 3 shows the relationship between daily maximum vapour pressure deficit and daily amplitude of stem diameter variations for two *C. montana* individuals (trees no. 876 and 885) during two different seasons with different climatic conditions: one wet period from 03.08.-14.08.2007 and one dry period from 26.11.- 08.12.2007.

The results document a positive correlation between the amplitudes of the daily stem diameter variations and mVPD in both periods. During the humid period, however, daily amplitudes of stem diameter variations are considerably smaller (< 0.07mm) than in the rainless period (> 0.07mm). Thus, the daily duration of stem water saturation which is a prerequisite for cambial activity (Deslauriers et al. 2007) is shorter during a dry period, implying that cambial activity is limited by available moisture even in such a humid ecozone (Bräuning et al. 2008).
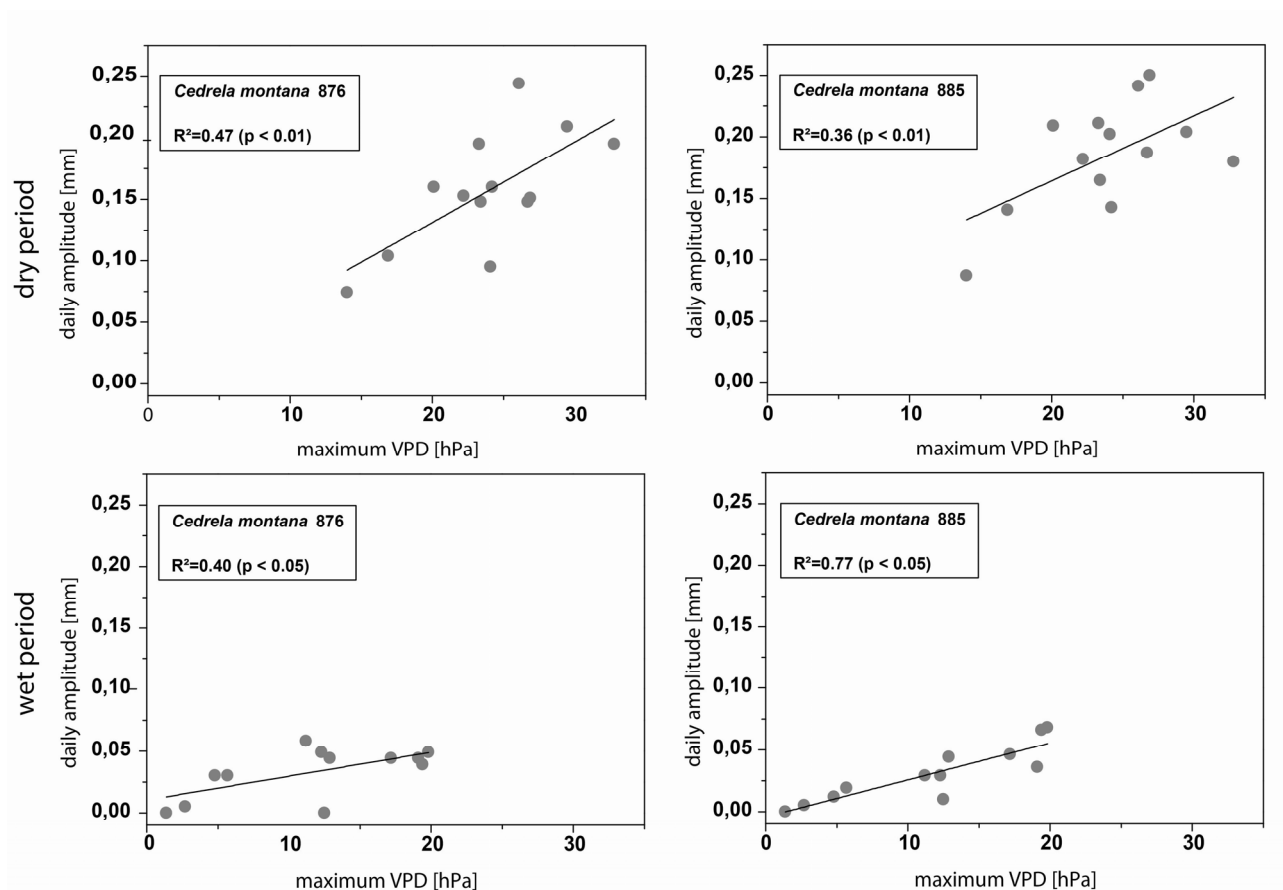
Figure 3: Linear regression between daily maximum vapor pressure deficit and daily amplitude of stem diameter variations for a dry period (26.11.– 08.12.2007) and a wet period (03.08. – 14.08.2007).

Competition-growth relationship

Figure 4 documents the influence of the improvement felling on the annual growth of *C. montana,* comparing the mean radial increments before (1976-2003) and after the treatment (2005). Surprisingly, the reference trees grew better after the fellings (*1976-2003: 2.31mm; 2005: 2.70mm*) whereas the PCTs remain approximately constant in growth (*1976-2003: 1.43 mm; 2005: 1.44mm*). It is worth mentioning that the reference trees and the PCTs differed in growth both before [t (36) = -4.34; p < .001) and after [t (24.64) = -2.66; p < .05] the treatment.

An enhanced light availability correlates negatively with annual tree growth (Figure 5). However, this tendency is only significant for the total amount of studied trees (N=38; r=-0.33; p<.05). Differentiated into the subgroups (reference trees and PCTs), only a similar tendency was found which was not statistically significant (p = n.s). In conclusion, the more a tree is exposed to light (Score 5), the lower is its annual growth rate (Spannl 2009). This effect is similar compared to the effect of a dry period as shown for the relationship between tree growth and climatic patterns (cf. Figure 3).
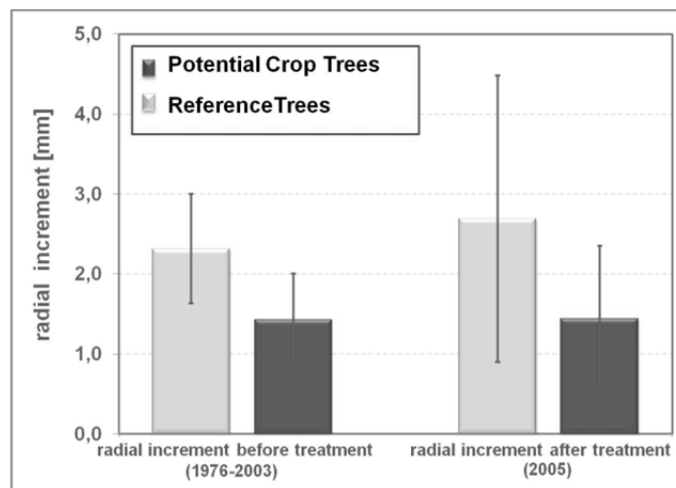
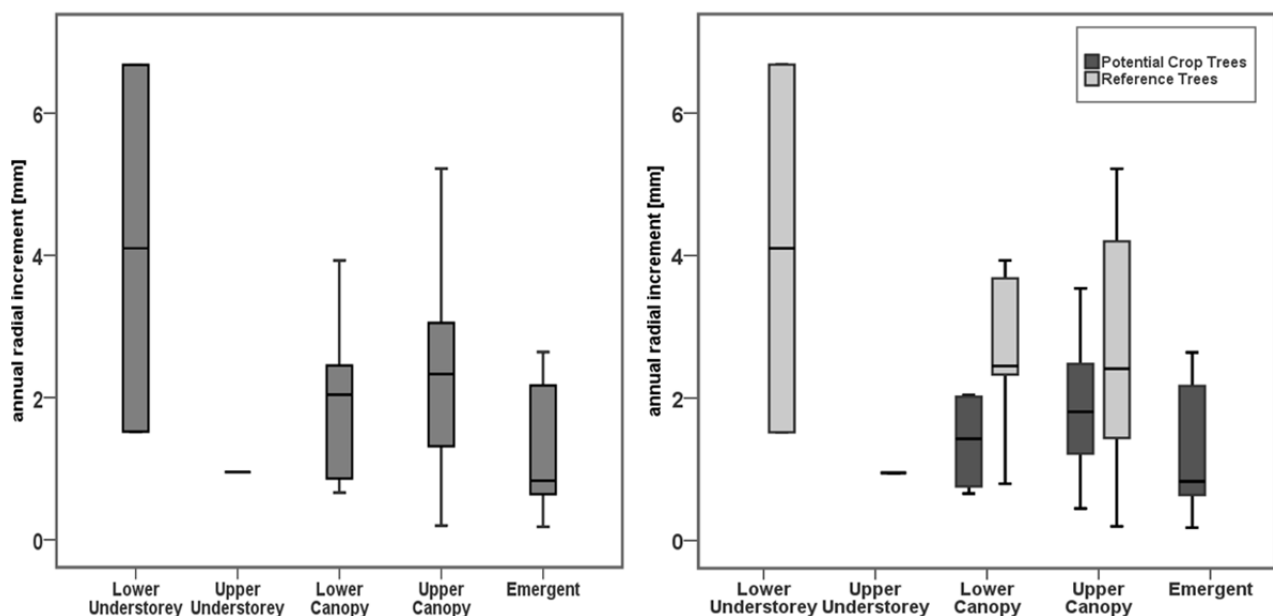*Figure 4: Radial increment of C. montana before and after the treatment (Reference trees: N = 18; PCTs: N = 20)*

Figure 5: Relationship between annual radial growth and light availability (left panel: all trees N=38; right panel: differentiated groups with RT: N = 18; PCT: N = 20).
Black horizontal bars represent the Median; Box limits give the 25-75% quartiles; Short horizontal bars indicate the minimum and maximum values.

Discussion and Conclusions

Based on these results for *C.montana,* we present evidence that tree growth in a tropical mountain forest is not determined by just one dominant environmental factor, but it is influenced by a complex interaction of several environmental factors. However, certain climatic patterns influence tree growth in a dominant way. During rainless periods with a high vapour pressure deficit, a decrease in diameter occurs. Despite the exposure to sunlight by the natural forest management experiment, the PCTs grew less than the reference trees. However, these results do not allow the general conclusion that the measure of the experiment had a negative effect on the PCTs. In contrast, other tree species like *Tabebuia chrysantha* (Bignoniaceae), which is also a deciduous broad–leaved tree species, doubled the mean annual growth from 2.7 mm/yr up to 5 mm/yr

(Bräuning et al. 2008) in the case of no over-shadowing competitor. Thus, *C. montana* might belong to a group of species showing a delayed reaction to the treatment.

In conclusion, the fellings caused a better exposure to light, but probably also stimulated transpiration and so water depletion within the trunk is possible for a short time. Taking this into account, the results of the competition-growth relationship and the climatic-growth relationship match well, considering the positive correlation between the amplitudes of the daily stem diameter variations and the amount of maximum vapour pressure deficit. However, to derive general conclusions about the controlling factors of tree growth in such an ecosystem, it is mandatory to extend the methodology in this research and examine additional tree species belonging to different plant functional types like evergreen broadleaved species or conifers. One first step are the intra-annual analyses of stable carbon isotopes is still in progress and we are expecting promising results.

Acknowledgements

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Soil type modifies climate-growth response of beech in Southern Britain

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Facing the change

There has been a long-standing recognition in Britain, and more widely in Europe, that common beech (*Fagus sylvatica* L.) can suffer apparent growth setbacks and poor canopy condition as a result of periods of low rainfall, especially if prolonged (Broadmeadow, Ray et al. 2005). Recent decades have seen emphasis placed on the deleterious effects of such climatic drought. More recently it has been hypothesised that these effects are becoming more severe and may continue to worsen under various modelled predictions of climate change in the UK. With an estimated warming between 2 and 5°C and a decline in summer precipitation (Hulme, Jenkins et al. 2002) the awareness of a change in the species distribution is growing. Early workers such as (Watt 1925) already commented on beech susceptibility to drought on shallow chalk soils in the UK, especially on those sites with a southerly aspect and high insulation. Beech growing on more retentive loam soils has apparently been much less seriously affected by these drought symptoms (Čermák, Matyssek et al. 1993; Leuschner 1993).

Beech has a high genetic potential for adaptation to drought. Beech populations in different climatic regions of Europe have been shown to display phenotypic drought adaptations, including various forms of sclerophylly (Bussotti 1997). It has also been demonstrated that there is genotypic variation between beech provenances, which can confer increased drought tolerance to populations which have become adapted to growth under conditions of frequent drought (Peuke, Gessler et al. 2006 ; Tognetti, Johnson et al. 1995; Volkmer and Rennenberg, 1997).

Beech trees in southern England show widespread symptoms of drought damage following the long dry summer of 1976, which had been preceded by a dry winter and spring season which did not permit full soil recharge following the relatively dry summer of 1975 (Aldhous 1981; Burdekin 1977).

The principle drought-related symptoms recorded in mature beech trees included: Mortality – especially of over-mature and infirm trees, reduced or halted apical growth/ changes in twig growth pattern, yellowing and early abscission of the foliage distinct from chlorosis, dropping of limbs, bark necrosis and exudation of a dark fluid from lesions, and increase in fungal diseases such as Nectria.

These symptoms were most often reported from old beech stands growing on shallow chalk soils or acid soils (including freely-draining sands and seasonally gleyed soils). Such conditions frequently occur in beech woodlands in southern England managed for amenity and nature conservation objectives. Alleviation of these effects in surviving trees was delayed by a period of several years. Later droughts in 1984-85, 1989-90 and 1995 saw recurrence/ amplification of these effects (Innes 1990)

It is therefore important to create a picture of stand growth, year-to-year variability, and climate growth reactions to estimate the reaction of a) *Fagus sylvatica L.* under different climatic conditions using a long time series analysis, b) comparing the extent of reaction on different soil types, and c) compare different beech species for climate-growth reactions.

Material & Methods

We sampled fifteen beech sites in southern Britain, located on different soil types. Sampling aimed for ten dominant trees following standard dendroecological methods (Stokes and Smiley 1968), however, on some sites this number was not reached on those sites were subsequently excluded from analysis. On each site a soil profile description was made including rooting depth. Sampling sites were selected in even-aged planted pure beech woodlands of at least 45-50 years of age apart from Burnham Beeches, Epping Forest and Workmens Wood which are mature beech woodlands.

Tree cores were prepared and measured in an annual resolution, using the program WinTSAP and a Rinntech measuring devise (both Rinntech, Heidelberg). Cross-dating for each site was done according to Fritts (1971). We calculated the annual correlations (R) for all sites (SAS 9.2, SAS Institute Inc., Cary, NC, USA).

Sites were characterised using the methods proposed for the Ecological Site Classification (Wilson, Pyatt et al. 2001) based on the study of the soil profile and ground vegetation assemblage. Five major soil types were included in the sampling programme: rendzinas, calcareous brown earths, mesic brown earths, free-draining acid soils and gleyed soils. The gleyed soils sampled are ranging from moderately fertile brown gleys to acid/ podzolic surface-water gleys. Sampling of the ground vegetation allowed to assign the sites to one of the three NVC beech woodland communities (W12, W14, W15) proposed by Rodwell (1991).

Rooting depth varies between sites decreasing from Rendzina over Podzol to Gley and Brown Earth. While some Rendzinas only provide 30cm of sub soil before the onset of pebbles and stone components, Brown earth provides in general well drained homogenous conditions to about a meter. Gley and Podzol vary greatly depending on site conditions with iron pans forming at about half a meter on some, resulting in being waterlogged in some seasons up to the humus horizon (e.g. Stourhead). Monthly climate data was obtained from the nearest weather stations operated by the Met Office. We used the program DendroClim (Biondi and Waikul, 2004) to analyse climate-growth trends from previous year August till October of the current growing season.

Results and discussion

Comparison of annual correlations of indexed site chronologies for all sites displayed three different types of dependencies: a) constantly positive, b) varying (Figure 1) and c) constantly negative. Positive correlations appeared to be between sites on the same soil type, whereas constant negative ones occurred when the soil type differed and the geographical distance was large. The varying correlation was present for sites in close proximity but on different soil types.
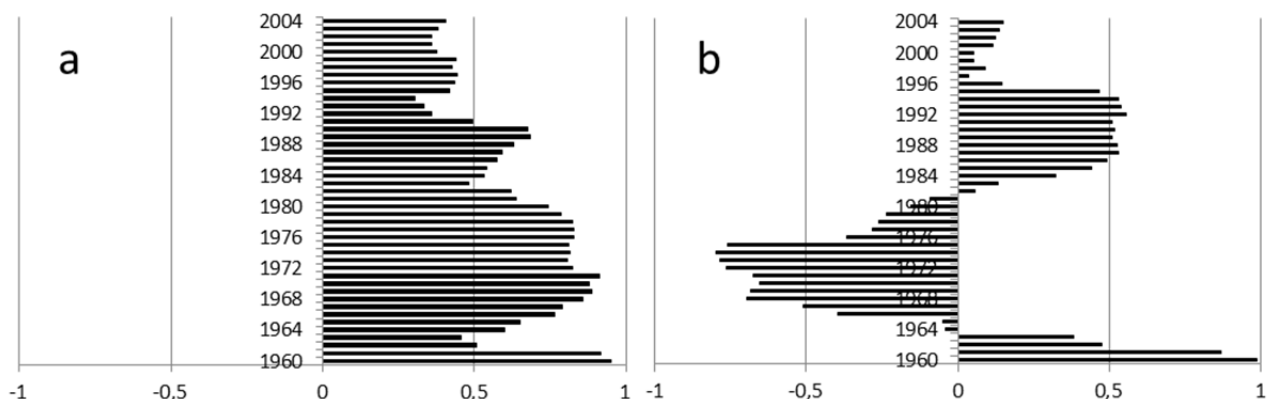

Figure 1: Correlation (R) between Epping Forest and Nower Wood both on Gley soils (a) and between Epping Forest and Workmens Wood on Gley and Rendzina respectively (b).

Due to the distance and the varying influence from maritime to more continental climate, we can assume factors other than climate dominating growth patterns. Correlations between sites do not remain stable over the whole investigated period for all site-to-site comparisons. While the same soil type does account for a stable correlation, a second influencing factor has changed. This is shown by the turn in correlations between sites of different ecological conditions (Figure 1). While the sites show a positive correlation till the mid-1960th a partially negative correlation dominates the next twenty years. From the mid-1980th however, a positive correlation appears, growth for several years and decreases again.

This pattern can be found for several sites and is confirmed by a step-wise cluster analysis (not shown). While up to the 1960s the ecological site conditions dominate the correlations between sites the following 25 years are defined by an increasing climatic influence separating the sites into the coastal and internal sites. Also weakening again as shown by the return to pre 60ies correlations, this is still the primary factor today.

Nevertheless known pointer years can be seen across the majority of sites (e.g. 1976) and we therefore concluded that climate can become dominating factor in extreme years. However, even the year 1976 does not appear as a pointer year for all sites and it is those sites, prone to water logging which are actually benefitting from warmer and especially drier conditions. Primary analysis show a difference in growth patterns and pointer years between sites on different soil types (Wilson, Broadmeadow et al. 2008) (Figure 2). However, signal strength varied and was not explained by soil type alone. We therefore analysed climate-growth relationships for all sites and compared the reaction to precipitation and temperature.
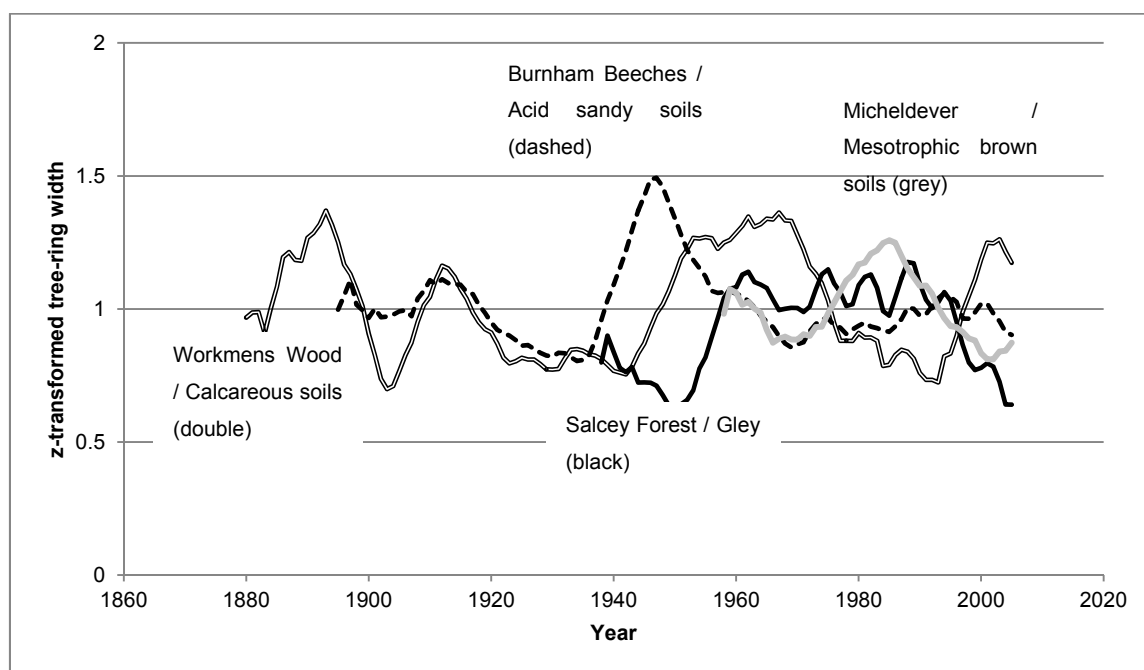

Figure 2: z-transformed tree ring width for typical sites on different soil types.

On calcareous soils (e.g. Workmens Wood) the significant positive correlations to precipitation wear off by the mid-1990s. A significant positive correlation to early spring precipitation is shown by sites on gley soils which last until the end of the 1980s when they started reacting positively to late spring/early summer precipitation. From the mid-1990s a negative correlation to early spring precipitation developed. Sites on mesotropic brown earth show no significant correlation with precipitation over the whole period, whereas correlations with temperature show the disappearance of any significant correlation after the 80s for sites on calcareous soils and the appearance of a negative correlation with summer temperatures on the gley soils. Sites on acid

sandy soils developed a significant positive correlation with spring temperatures, whereas for the sites growing on calcareous soils the significant positive correlations wear off by the end of the 80s and only occasional positive correlations to autumn temperature appear.

Conclusions

The results of this study broadly support the advice given by Pyatt et al (2001) as to the potential suitability of beech as a productive tree species within its British native range. The species is not to be recommended for use on sites with significantly impeded soil drainage in the winter season (SMR being Very Moist, Wet or Very Wet), especially where increased winter rainfall and more frequent summer droughts due to climate change may be expected to exacerbate the risk associated with root truncation. Use of beech on sites with slightly impeded drainage due to clay layers below 50cm depth (SMR being Moist) appears to carry a somewhat increased risk of restricted growth and drought-induced necrosis, but this may be acceptable to the manager in some cases, especially where there is a site record of successful beech silviculture, as on the argillic clay soils of the Chiltern back slopes. These sites naturally carry beech woodland of NVC W14/ *Fagetum rubosum* type, but do often have impeded drainage at depth. However, our study show that beech growth is likely to improve on sites with previous water logging which is lessening due to warmer and dryer summers. Nevertheless, the risk of root damage in winter can persistent on some sites.

On freely draining soils beech will generally remain a suitable species choice, even under predicted scenarios of increased summer drought, unless there is an abnormally low available water capacity. The results of this work suggest that this is primarily a problem on coarse sandy soils carrying NVC W15/ *Fagetum ericetosum* beech woodlands where pore size distribution is skewed towards the larger end of the range and water holding capacity per unit depth is restricted (SMR being Moderately Dry). Studies into the spontaneous rooting depth of beech on such sites would enable more accurate estimates to be made of their effective available water capacity (AWC). Some old beech woodlands on such sites show at present signs of decreased stem density and increased canopy retreat, which may represent endogenous responses to inadequate moisture supply and excessive root competition for moisture.

Many beech woodlands of the NVC W12/ *Fagetum calcicolum* occur on shallow rendzina soils over Cretaceous chalk (North and South Downs, Chilterns) or Jurassic oolitic limestones (Cotswolds). While the available water capacity (AWC) of the soil profile as calculated by the methods proposed by Pyatt et al (2001) is undoubtedly low, there is evidence that such soils can have access to upward-moving water from porous strata immediately below. Thus the effective AWC available to a tree crop may be much larger than that calculated for the soil profile, mitigating any anticipated drought risk. This has been demonstrated for the Cretaceous chalk in a single site study in a beech woodland of similar type to those included in the present work (Roberts and Rosier, 2005), but no equivalent work has been conducted in beech woodlands over the Jurassic oolitic limestones. Further studies of this kind across the chalk and limestone topographic range would be of value to fully understand the impacts of different soil types on beech growth.

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SECTION 3

GEOMORPHOLOGY

Reconstruction of landslide activity in the Keprnický valley, Eastern Sudetes, Czech Republic with a tree-ring eccentricity index

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Introduction – pattern of eccentric growth of Norway spruce (*Picea abies* Karst.)

Trees growing on unstable slopes tend to be tilted and have deformed stems. They can be tilted or bent under the influence of various types of geomorphic mass movement (e.g. lateral spreading, landslides, debris flow). The character of the deformation produced depends on the direction of tilting: upslope or downslope (Fig.1).

The Norway spruce (*Picea abies* Karst.) trees analysed in the case study from the Keprnický site can have straight, s-shaped or "pistol-butted" stems when tilted downslope. Spruce trees tilted upslope usually have straight or "pistol-butted" stems. They also have deformed stem cross-sections: oval, elongated parallel to the slope inclination (Fig. 1A-B). Spruce trees growing on stable slopes have straight vertical stems without significant deformations of the stem cross-section (Fig. 1C).
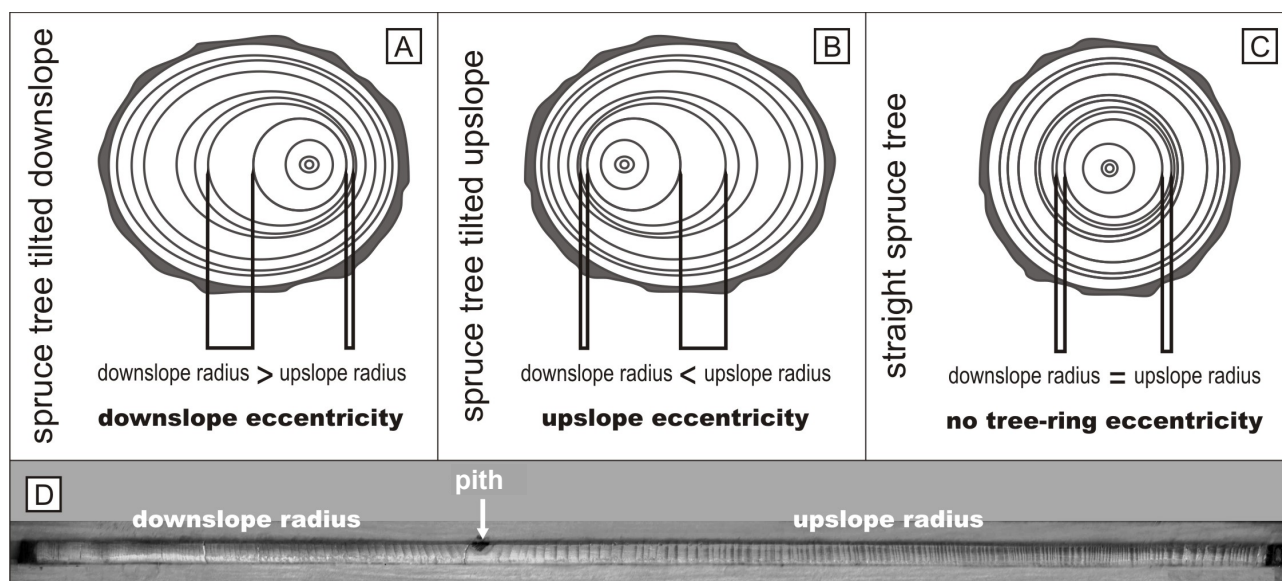

Figure 1: Development of: A – downslope eccentricity of tree rings in spruce tree tilted downslope, B – upslope eccentricity of tree rings in spruce tree tilted upslope, C – lack of eccentricity in straight tree stem (example: Picea abies Karst.). D – A increment core sample showing clear upslope eccentricity.

External deformations of stems affect the structure of the wood produced and eccentric growth develops. The pith is displaced as a result of this (Fig. 1D). Coniferous trees such as Norway spruce produce wider rings on the lower (bottom) part of the stem, that is, the upslope part of the stem, if bent upslope (Fig. 1B, D) and the downslope part of the stem, if bent downslope (Fig. 1A). Anatomical disturbances caused by tree tilting are most distinct in the axis parallel to the deforming force (mass movement). The first tree ring showing eccentricity provides information on when the tree started to react to the impact of the mass-movement (Braam et al. 1987a, 1987b). Similar results for eccentricity in coniferous trees, as in Keprnícy site, were also obtained by

Schweingruber (1996) for spruce, Stokes and Berthier (2000) for *Pinus pinaster* Ait. and Krąpiec and Margielewski (2000) for spruce and fir.

The Keprnícký study site

The studies were conducted in the mid-mountain range of the Hrubý Jeseník in the Eastern Sudetes, Czech Republic (Fig. 2A), in the Keprník-Šerak massif (1423-1351 m a.s.l.). The bedrock of the Keprnícký valley is composed of metamorphic rocks (schists and gneisses within the study site). The Keprnícký sream belongs to the Oder (Baltic Sea) basin. The average annual precipitation totals for the period 1961 to 2000 are 921 mm and 1025 mm for the two nearby gauging stations Heřmanovice and Rejvíz, respectively.
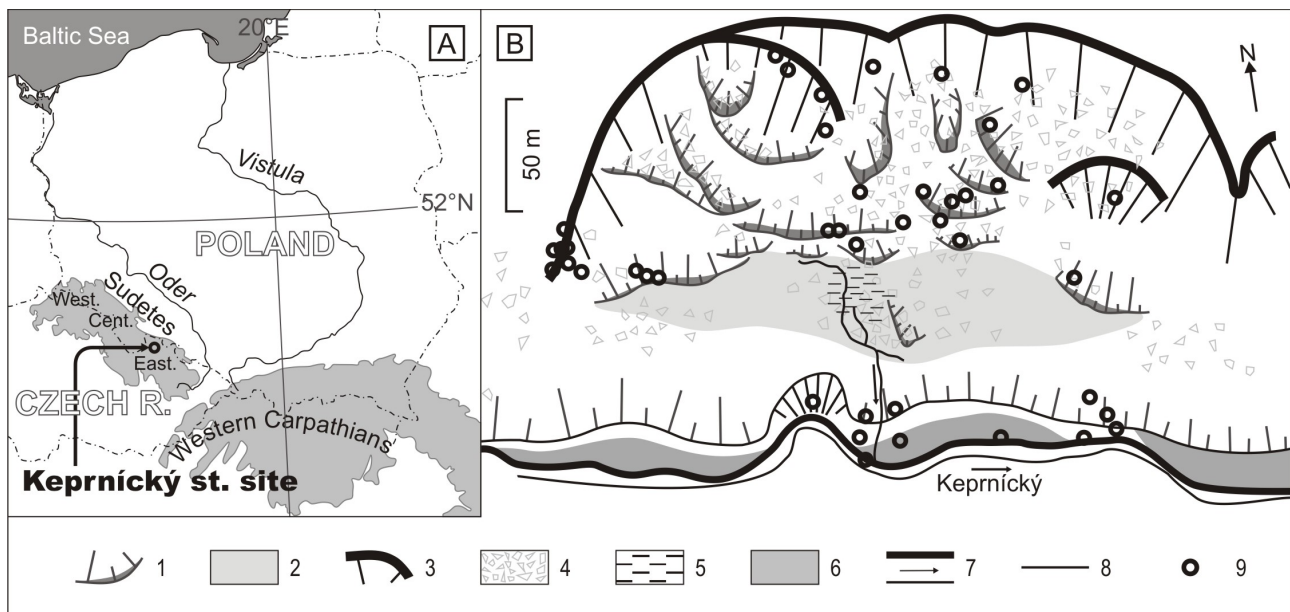

Figure 2: A – Location of the Keprnícký study site in Eastern Sudetes and Czech Republic. B – Geomorphic sketch of the Keprnícký study site: 1 – landslide lobes, 2 – collapsed block, 3 – headscarp, 4 – scree slopes, 5 – boggy areas, 6 – alluvial bars, 7 – stream channels, 8 – bank undercuts, 9 – sampled trees.

The studied slope is located in the middle, transitional section of the Keprnícký valley. The relief of the slope suggests the presence of past and contemporary mass movement activity, probably deep-seated landslide (~200 m long and ~300 m wide) descending from a mountain ridge (~910 m a.s.l.) into a valley floor and stream channel (~850 m a.s.l.). The study includes a whole landslide, composed of a single niche and single tongue (Fig. 2B). A reference site was also selected in the upper section of the Keprnícký valley. It is located 1 km away from the study site, on a slope with an orientation and inclination similar to the study site. The reference slope has a smooth surface and signs of deep mass movements such as landslides were not found.

Both the study and reference sites belong to the lower montane vegetation belt in which naturally deciduous beech forests with common beech (*Fagus sylvatica* L.) and European silver fir (*Abies alba* Mill.) occur. However, currently the site is covered with artificially planted, monoculture forests of Norway spruce.

Methods of the dendrochronological study

A total of 42 trees were sampled on the landslide slope and another 12 at the reference site. Two cores were taken from each tree using a 4 mm standard growth increment borer. Cores were taken at breast height in one axis parallel to the slope inclination. The procedure applied enabled us to obtain tree-ring data from the upslope and downslope parts of the stems. All samples were taken

from Norway spruce. Only trees visually assessed as healthy were sampled. The sampling concentrated on trees with stems as deformed as possible. Tree-ring widths obtained for the up- and downslope sides of single trees were compared and converted into an eccentricity index of tree rings using the formula:

$$Ex \ [mm] = Ux - Dx; \qquad\qquad [1];$$

when Ex [mm] > 0:	upslope eccentricity;	$Eix \ [\%] = (Ex \ / \ Dx) \ x \ 100\% > 0;$ [2a];
when Ex [mm] = 0:	lack of eccentricity;	$Eix \ [\%] = Ex \ [mm] = 0;$ [2b];
when Ex [mm] < 0:	downslope eccentricity;	$Eix \ [\%] = (Ex \ / \ Ux) \ x \ 100\% < 0;$ [2c];

where:

U is the tree-ring width in the upslope part of the stem [mm];
D is the tree-ring width in the downslope part of the stem [mm];
E is the eccentricity of tree ring [mm];
Ei is the eccentricity index of the tree ring [%];
x is the year (annual tree ring).

The moments of slope movement are presumed as being recorded as abrupt, year after year, changes of the eccentricity index value:

−   in upslope eccentricity – increases in the index value (from positive/negative to positive),

−   in downslope eccentricity – decreases in the index value (from positive/negative to negative).

The relative yearly change of the index value was used to date the most probable landslide episodes. To facilitate the dating the yearly variation of eccentricity index was calculated (vEix [%]), as the difference between the index value for a certain year and for the year before:

$$vEix \ [\%] = Eix - Eix\text{-}1; \qquad\qquad [3];$$

where:

Ei is the eccentricity index of tree ring [%];
vEi is the yearly variation of eccentricity index [%];
x is the year (annual tree ring).

Indicators were calculated for each tree ring in the samples taken. The values obtained for all trees and years are presented as linear and bar graphs (e.g., Fig. 3). Landslides were identified by comparing them against the results from reference slopes (yearly variation for all annual rings in all reference samples). Arithmetical means and standard deviations were calculated separately for the set of increases (vEi > 0), and decreases (vEi < 0). The values of means plus deviations were used as thresholds for determining the most distinct changes of index values at study sites. The thresholds for the Keprnický reference site were: -59.54% (downslope episodes) and 56.38% (upslope episodes).

After considering the directions of changes (only increases into positive values and decreases into negative values could be included), these thresholds were used for dating the most likely landslide events (Fig. 3). Other cases (decreases from positive to positive values or increases from negative to negative) were interpreted as trees recovering after periods of destabilization due to earlier mass movements.

The tree-ring data were compared with precipitation totals (Czech Hydro-Meteorological Institute; Fig. 4) which were derived from the gauging stations Rejvíz and Heřmanovice located 15 and 17 km away from the study site, respectively. Data for June, July, August and September were used

for the analysis – the months with the highest precipitation probably responsible for activation of landslides in the region studied.
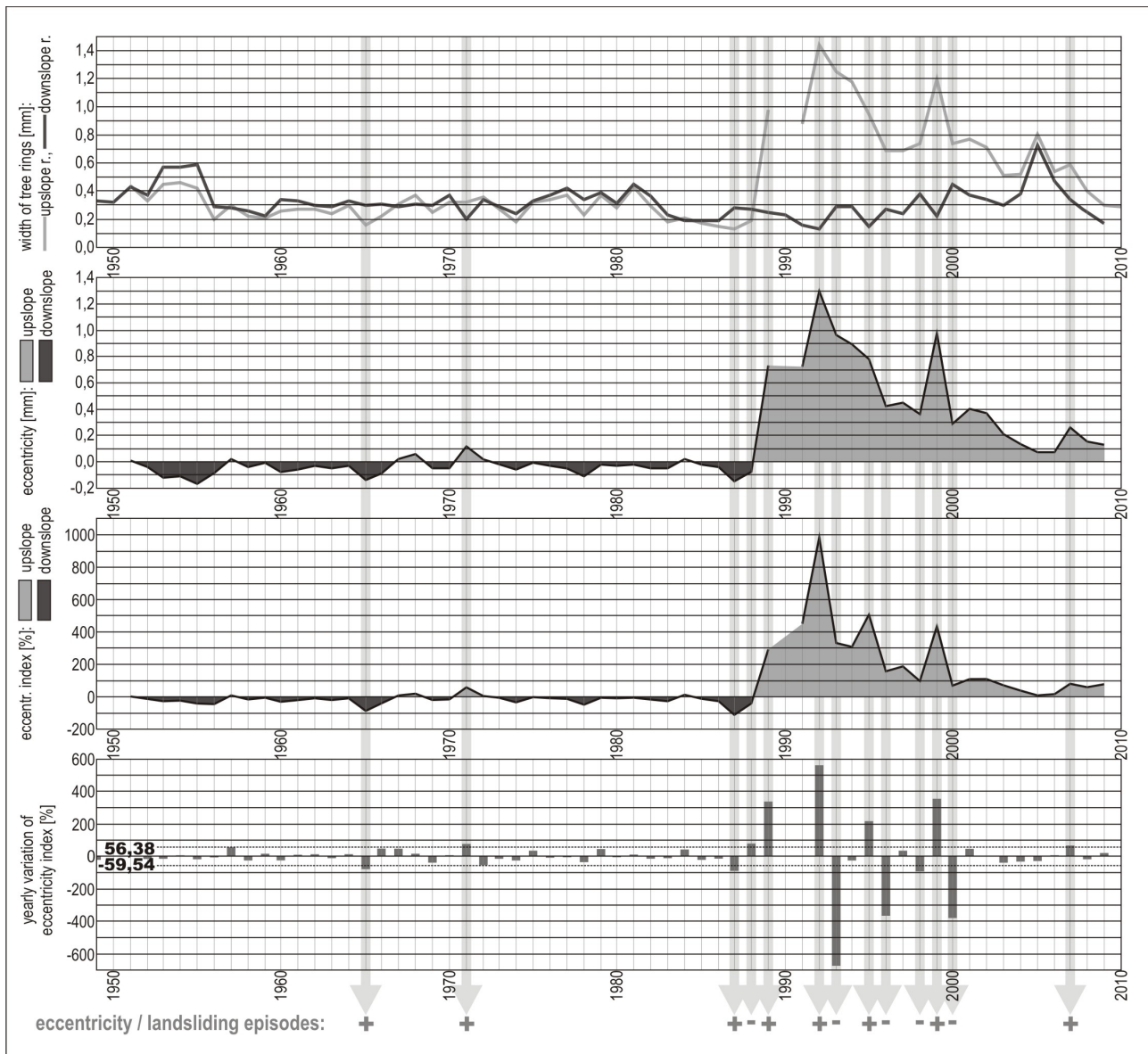

Figure 3: An example of a tree-ring series transformation from ring widths into eccentricity, eccentricity index and its yearly variation, with eccentricity episodes dated on the basis of thresholds from the reference site (56,38% and -59,54%).

A dendrochronological record of landslides at the Keprnícký site

At the Keprnícký site the series of eccentricity data date back to the first half of 19th century. 31 of the total 42 eccentricity series date back to at least 1900. The oldest landslide signal dated is 1836. The eccentricity patterns of trees growing at the reference site are different from the landslide slope (Fig. 2). The eccentricity indices for spruce growing on stable slopes oscillate around 0%, rarely exceeding ±100% during the whole period of the trees' lives (e.g., before 1989 in Fig. 2). Individual years or short periods with upslope and downslope eccentricity occur alternately. This result suggests a constant balancing of the trees, which maintain a near-vertical position and equilibrium on a slope while fighting the impact of wind, snow cover and the increase in tree mass with time due to its growth. Some trees growing on the Keprnícký landslide slope show the same

pattern of eccentricity index as in the reference site in the first period of growth. More or less abrupt changes are observed after this period (e.g., dramatic increases of the indices after 1989 in Fig. 2) and may be interpreted as a disturbance of the equilibrium of trees. At the Keprnický study site the maximum upslope eccentricity index value of a single annual ring is 3450%, in the case of downslope eccentricity it is -1011%. Some trees sampled do not show the initial period of stability described which indicates that from the beginning of their growth the slope was unstable.
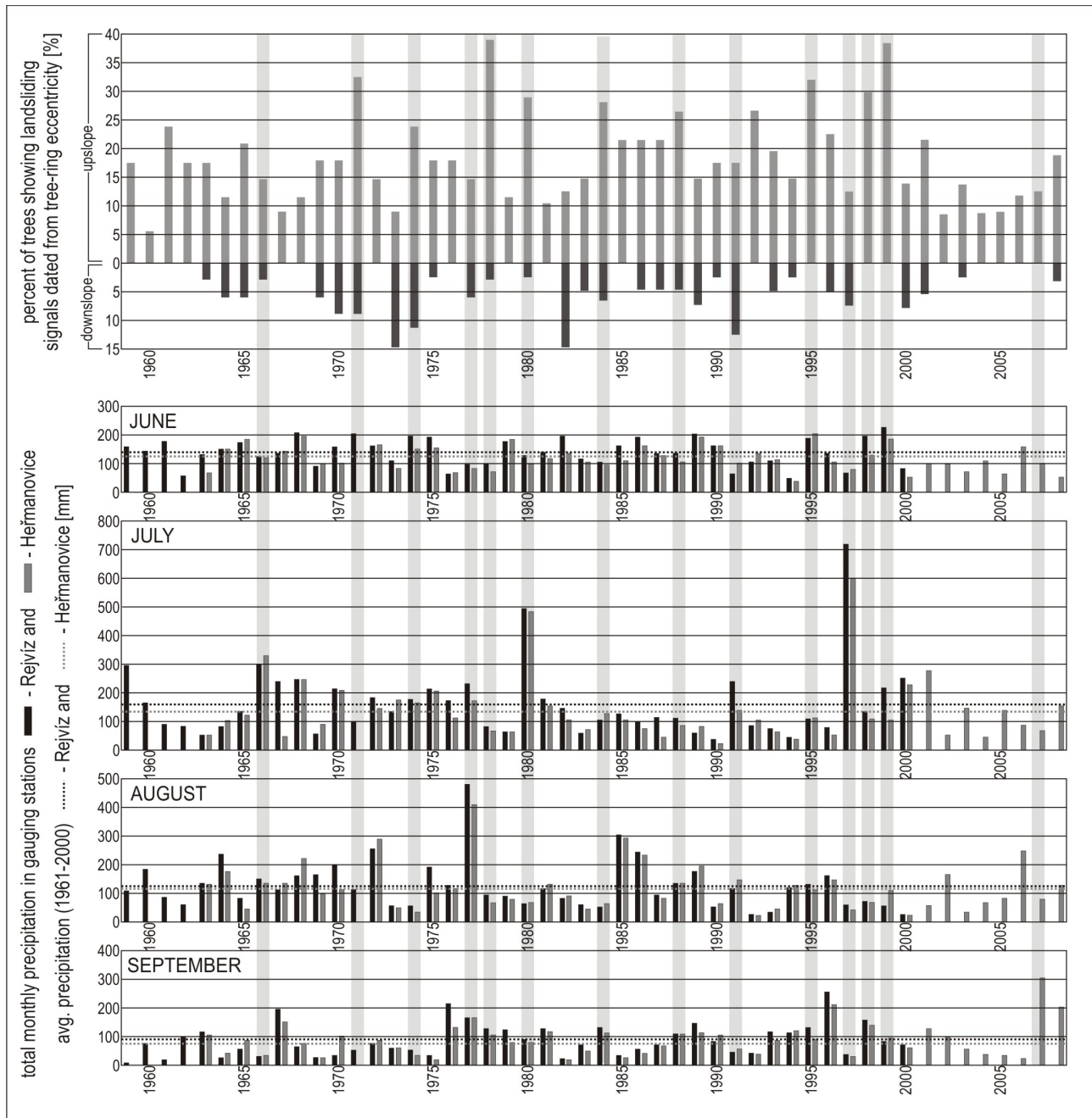

Figure 4: Comparison of landslide signals dated at the Keprnický study site with precipitation data for the period 1959-2008 (light grey stripes – years with the highest number of signals or highest precipitation).

The total number of mass-movement episodes identified via thresholds (values based on reference results) is 697 (in 42 trees, during 174 years). 574 of these (82%) are upslope episodes. The temporal distribution of landslide episodes is uneven. In general it increases along the time axis from 1836 to 2001 in line with the increase in the number of available time series. The first peak period of landslide activity at the Keprnický site is 1918-1945 with up to seven signals per year,

with an absolute peak between 1929 and 1945. The second peak is identified for 1958 to 2001 (up to 15 periods per year) with an increased intensity between 1971 and 1999.

Due to the limited availability of the precipitation data the period 1959 to 2008 was chosen for detailed analyses of the relation between eccentricity, landslide episodes and meteorological conditions.

Discussion and conclusion

Temporal variability of landslide episodes at the Keprnický site compared with precipitation data

We have compared the amount of up- and downslope landslide signals (percent of trees with signals in the whole population sampled) with the precipitation record (Fig. 4). In case of the Keprnický landslide, the highest amount of eccentricity signals was found for the years 1978 (>40%), 1971 and 1999 (~40%).

In case of the year 1999 the precipitation for June in the area was above average and The two preceding years (1997-1998) are also well known for their catastrophic summer floods, even if the amount of eccentricity signals was not very high then. It may be that the initial mass movements took place in 1997-1998, and, by increasing bedrock instability, prepared the slope for the larger landslide in 1999.

A clear example for a landslide signal caused by high precipitation is 1980 (>30%) with large amounts of precipitation in July (Fig. 4). However, years with a many eccentricity episodes are not always characterized by large monthly precipitation sums, for instance the years 1971, 1974, 1978, 1984 (>35%), 1988 (>30%), 1991-1992 (30-25%) and 1995 (>30%). This missing link between the precipitation data and the landslide events found in our data set might be due to a strong local variability of precipitation, especially because of often occurring summer storms. It also hints to the fact that landslides can probably be triggered by a single downpour which may not be obvious in total amounts of monthly precipitation (e.g., only slightly exceeding means in Fig. 4). Good examples for such phemonemana are the events in April 1971 which, according to Štekl et al. (2001), were catastrophic in the Keprnický valley, and in July 1991 when torrential rainfall was observed in the study area resulting in the activation of debris flows (Gába, 1992).

In some cases high numbers of mass movement signals are recorded one or two years after the years in which rainfall events were recorded, for example, the above mentioned year 1999 after catastrophic summer floods in 1997-8, 1988 after a wet August in 1987, and 1992 after a torrential rainfall in July 1991 (Fig. 4). The reason for such delayed reactions can be increasing slope instabilities after initial mass movements during the catastrophic rainfall event (landslides can later be triggered by smaller precipitation in following years, as was probably the case in 1997-9. Alternatively, the delay might be due to a prolonged, strong tree reaction caused by a particularly catastrophic event in the first year as probably occurred in 1991-2. Another reason might be that the landslide occurred at the end of the growing season and thus the tree reaction was delayed until the beginning of the following spring, as probably occurred in 1987-1988 following heavy rainfalls in August 1987).

Acknowledgments

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Dendrogeomorphological analysis of gully erosion in different types of landscapes.
Examples from Szeskie Hills and Gorce Mountains

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Introduction

During the last few decades intensive rainfalls are observed more frequently. Gully erosion could be one of the effects of heavy rainfalls. It is proven that this kind of geomorphic process is tending to occur and transform mid-mountain areas (Wrońska-Wałach 2009). Gully-like valleys are also found in the area of young-glacial relief in the lowlands (e.g. Morawska 2011, Smolska 2007), but their development tendencies and dynamics remain still undefined.

Dendrogeomorphological method helpful tool to analyse different geomorphological processes (Alestalo 1971, Gärtner et al. 2001). Gärtner (2003, 2006, 2007) established the methods of root anatomy changes which enable to reconstruct extreme as well as continuous processes. Till now, analysis of roots anatomy from numerous tree species have been used to estimate the magnitude and frequency of various geomorphic processes and gully erosion was one of the most frequent subject for such investigations. Dendrogeomorphological analyses from roots were mostly based on coniferous species (Bodoque et al. 2005, Buchwał 2008, Carrara & Caroll 1979, Corona et al. 2011, Gärtner 2006, Perez-Rodriquez et al. 2007, Rubiales et al. 2008,). Roots from deciduous species were taken into account less frequently and consider primarily ring or semi-ring porous species (Hitz et al. 2008, Malik 2008, Malik & Matyja 2008).

The main aim of the following study is to analyse the role of gully erosion in transformation of small gully-like valleys in different types of landscapes. That's why a dominant species were taken into consideration. In the Gorce Mts. spruce (*Picea abies* L. Karst) is the dominant species (Chwistek 2001), therefore the analysis of gully erosion is based on the analysis of the anatomy changes within spruce roots. In Szeskie Hills, which represent young-glacial landscape, deciduous, diffuseporous species are predominant, mainly common hornbeam (*Carpinus betulus*, L.).

Study area

Gorce Mountains

One of the study areas is located in the Southern part of Poland (Fig. 1) – Outer Carpathian Mountains (Gorce Mts.) Gorce Mts. with height of about 1200 m a.s.l. and slope of about 25-30º are representative for the middle mountains. The study site was established in the headwater area of Lepietnica stream – 1160-1230 m a.s.l (Fig. 2a). Small gullies which were selected for the analysis are the most common feature in the study area. Gully which was taken under consideration has diverse longitudinal profile with steps developed on rock debris, woody debris, roots and rock outcrops. Maximum deep of gullies amount 6 m, and width is about 1,7 m.

Figure 1: General localization of study areas.

Szeskie Hills

This region is situated in North-East Poland (Fig. 1) within extent of LGM (Last Glacial Maximum). It represents vast plateau of kame hills which are higher than surrounding lakelands with peaks on over 270 m a.s.l. and morainic plateau level of ca. 200-220 m a.s.l. (Fig. 2b). Szeskie Hills is a region with the highest gullies density among whole North-East Poland (Morawska 2011), gullies in this area form dendritic networks that are incised in steep (10-20°) kame slopes. Most of them are covered by hornbeam-spruce forests. Examined gully is located on Rudzie Hill in central part of the region. It is approximately 500 m long, its gully head has V-shaped cross-section with young box-like incision over 1 m deep. Downstream, gully bottom widens and it forms a cascade of small basins and steps developed on woody and erratic boulder debris. Near the gully mouth three terrace levels can be distinguished and the bottom is 12-18 m wide (Fig. 3).
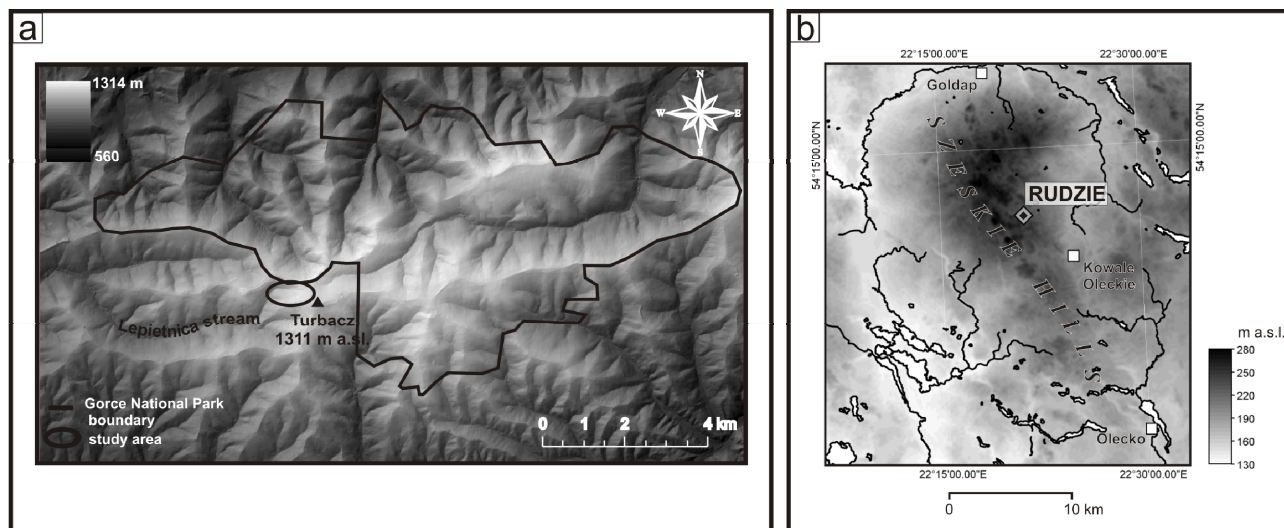

Figure 1: Detailed localization of study areas: a) headwater area of Lepietnica stream, b) Szeskie Hills.

Methods

In the headwater area of Lepietnica stream (Gorce Mts.) detailed geomorphological mapping was conducted. Steps, pools, boulder steps, dams of coarse woody debris and roots as well as bank undercuts and small slides were taken under consideration. 9 spruce (Picea abies L. Karst) root

samples were collected from sides as well as from the bottom of the gully with fresh signs of contemporary activity.

In case of Rudzie Hill, two sites, representative for two upper parts of gully was examined to estimate contemporary erosion rates and changes within gully morphology (Fig. 4). 11 samples of exposed and partly-exposed roots of common hornbeam (*Carpinus betulus*, L.) were collected mainly from the gully bottom. Additionally, 7 samples from depth of 5 to 20 cm below ground surface were taken from 2 buried roots, to asses and infer how common hornbeam roots react to the exposure.

Roots were polished and cut into 15-20 μm slides using Microtome "GSL 1". Microanalyses of roots were performed according to the procedure developed by Gärtner et al. (2001) and F. Schweingruber (1990). Structural changes in roots were examined via measurements of cell lumen areas using WinCell Pro and Regular (Regent Instruments).
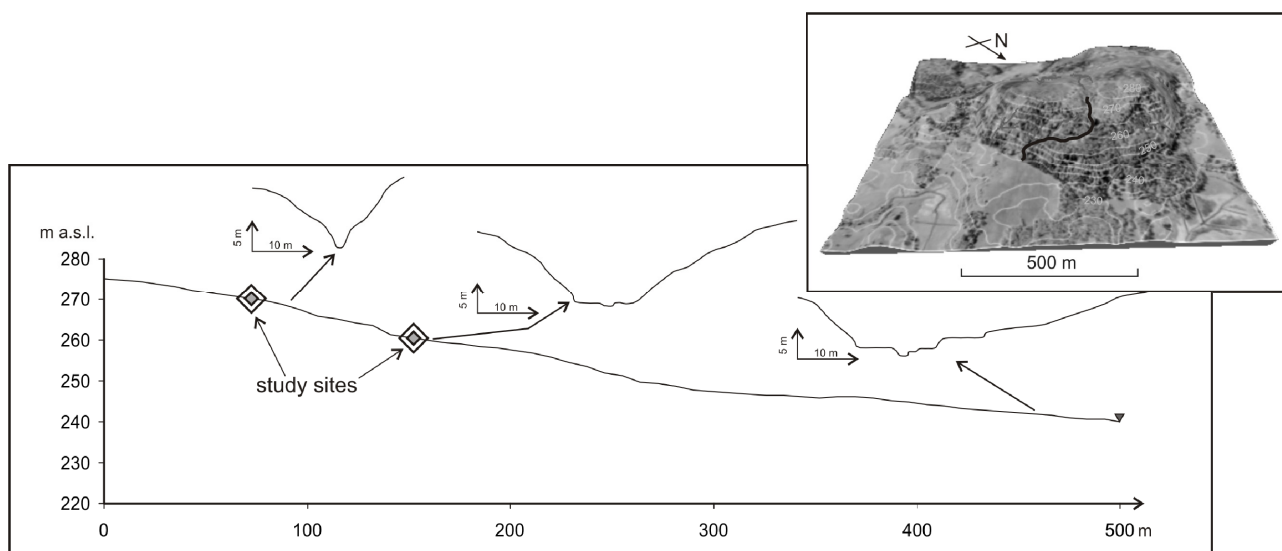

Figure 2: Rudzie Hill overall view (blockdiagram on upper right).Longitudinal profile of gully investigated.
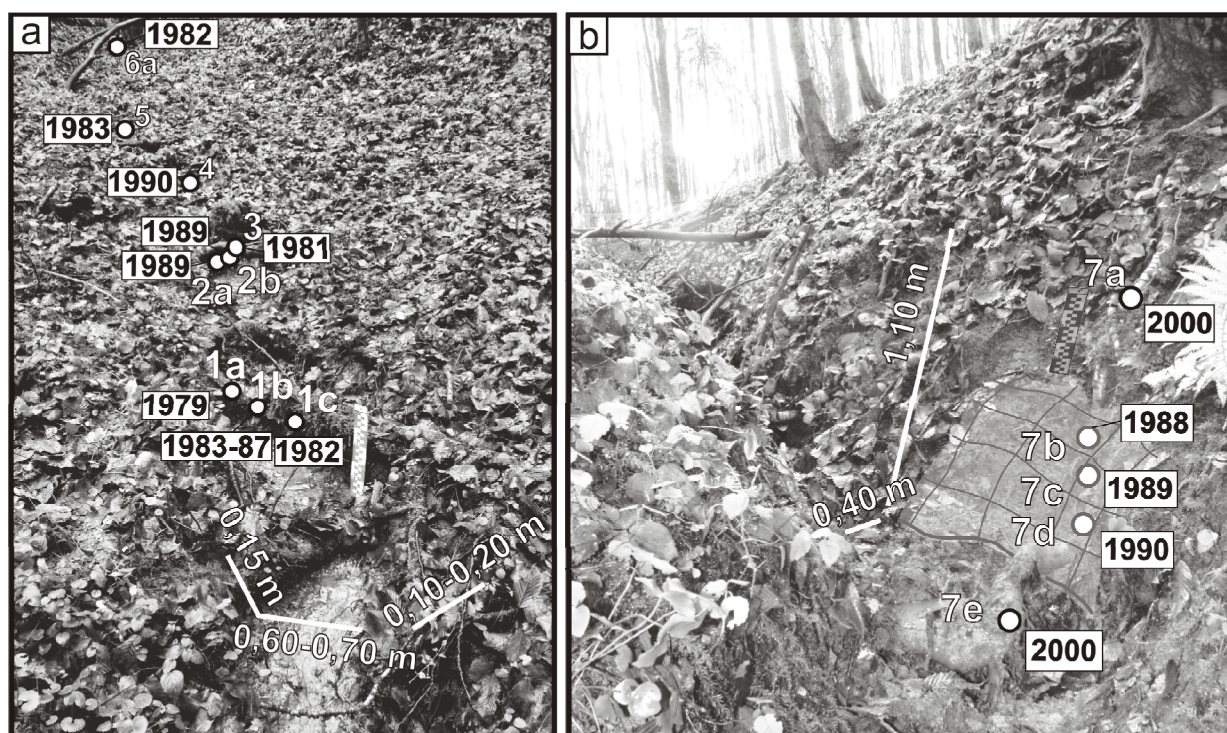

Figure 3: Gully on Rudzie Hill investigated sites: a) basin in the middle part of the gully, b) young incision within v-shaped gully head. Samples marked with circles. Years of exposure are marked in brackets.

The root samples were treated in a different way depending on the species. Spruce root samples were rigorously examined with special attention being paid to changes in earlywood (EW) lumen size (Gärtner et al. 2001, Gärtner 2003, Gärtner 2007). For the Carpinus betulus which is a diffuseporous species, an analysis of all the structural changes in the wood was performed. This analysis comprises both measurements of vessels and fibres (for limited number of samples) size and changes in tree-ring structure without distinction for early- and latewood. According to Hitz at al. (2008) reduction of fibres cell lumen area to approximately 50% below the long-term average is the indicator of an exposure.

Results and Discussion

Analysis of spruce roots showed their exposition during two subsequent periods: 1970/1971 and 1972/1973 (7 of 9 roots). Cells measurements proved sudden exposition of all root samples (Fig. 5). Furthermore, all analyzed samples had erosional scars. Therefore obtained ages of spruce roots exposition could be related to the occurrence of the major geomorphic events which transformed shallow valleys and slopes in the Lepietnica headwater area. During that time gullies were deepen of about 1,5 m and over 334m^3 of material have been eroded and removed from gullies. First event started in the valley head as a translational slide and further down transformed into torrential flow. Roots analysis proved that during first event in 1970 shallow valley was incised and gully have been formed (Fig. 6). During second event previously exposed roots formed the obstacles for transported mineral and organic material and in the consequence were dammed. Such transformation could be the consequence of the so called clustering processes (Starkel 1996). Analysis of the distribution of different landforms (steps, pools, debris dams) in relation to the exposed roots proved important role of the localisation of trees and dense root structures in the establishment of gully segments. Hanging, exposed roots were able to dam large boulders, cobbles and fine woody debris and form steps. Immediately below the steps pools were formed (Fig. 6). That results in the formation of irregular longitudinal profile of gully. Since last episode in 1972 there is now evidence of other events. Therefore, we are able to believe that the structure of once transformed gully was able to remain permanent for long (about 38-40 yrs) period.
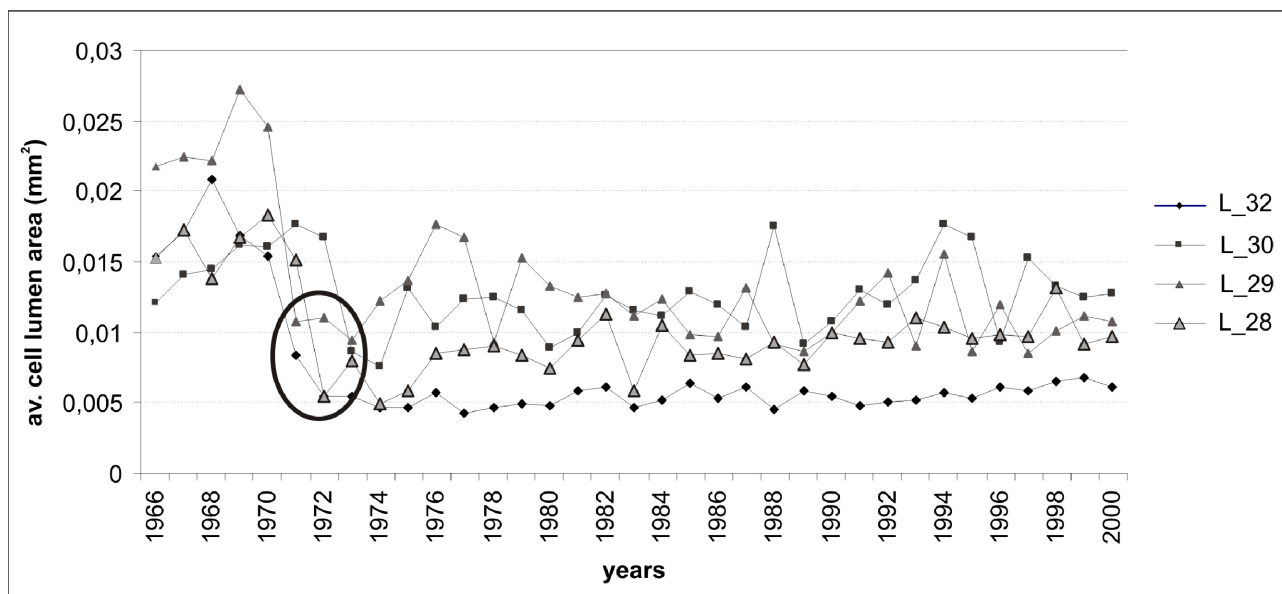

Figure 4: Graph showing annual values of the mean cell lumen area size of earlywood, within roots taken from a gully. Ellipse indicates the group representing the 1970-1972 years of exposure.
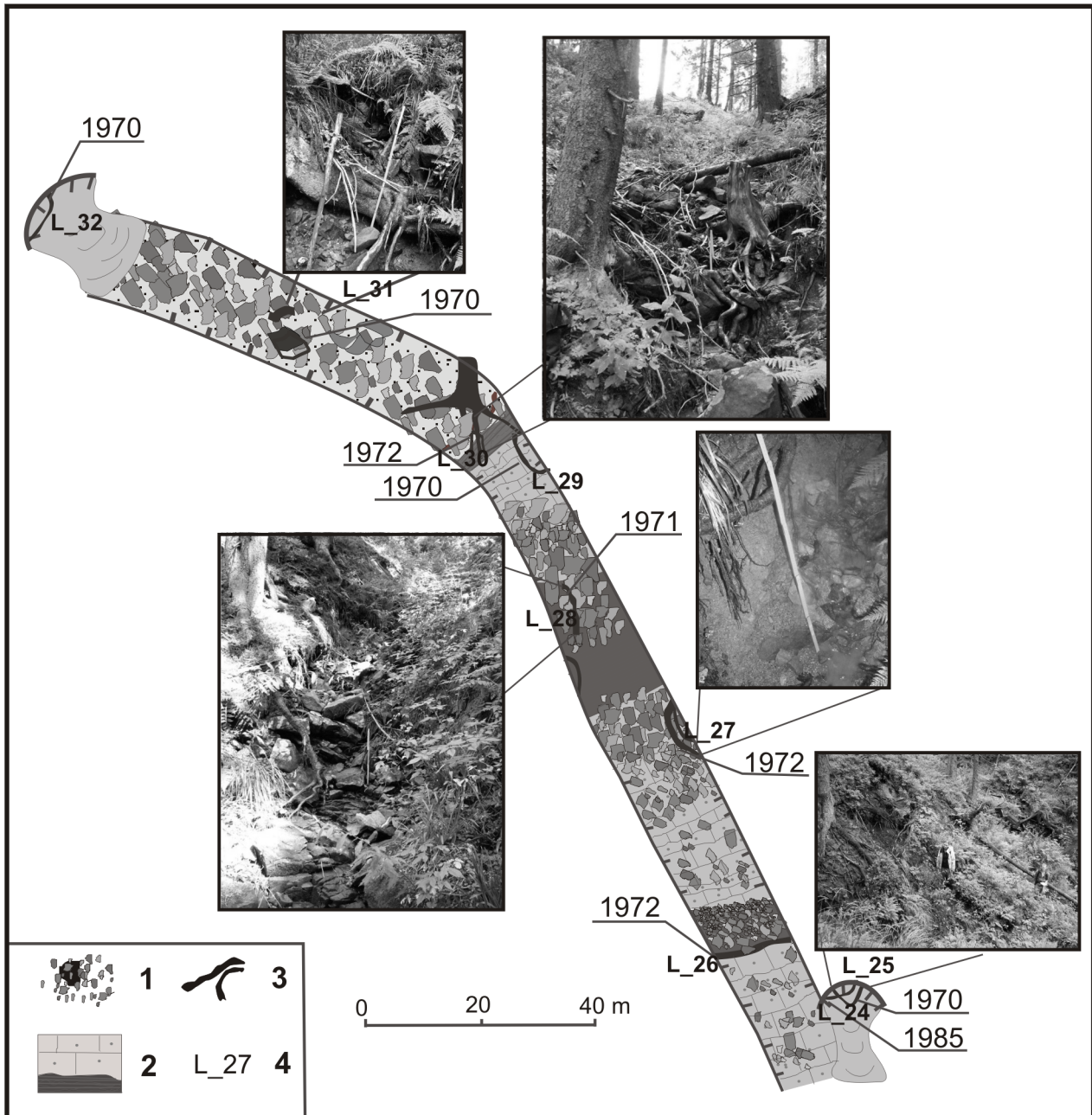
Figure 6: Geomorphological outline of gully: 1 – large and fine rock debris, 2 – rock outcrops: sandstones and schist, 3 – exposed root samples, 4 – number of samples.

Studies on common hornbeam roots reaction to the exposure revealed drastic (over 50%, up to 70% of previous cell lumen size) changes in the cell lumen size of vessels due to exposure and further decreasing tendencies during subaerial growth of the root (Fig. 7a). In case of fibres, changes of their size linked with exposure are less noticeable. They're masked by fibres size increasing tendency and relatively large fluctuations of fibres size year by year (Fig. 7b). In this case, changes in vessels cell lumen size were more significant for inferring geomorphological processes and were taken into account in further interpretations.

Within the basin analysed in the middle part of the gully, two distinct periods (1979-82 and 1989-91) of intense gully erosion could be distinguished. Structural changes of wood suggest that erosion processes were small-scale and episodic. Contemporary channel in basin bottom is only 0,6 m wide and up to 0,2 m deep, and the roots exposed over it express exposure dates from 1979 to 1991. What is more, many of examined roots revealed progressive process of exposure that

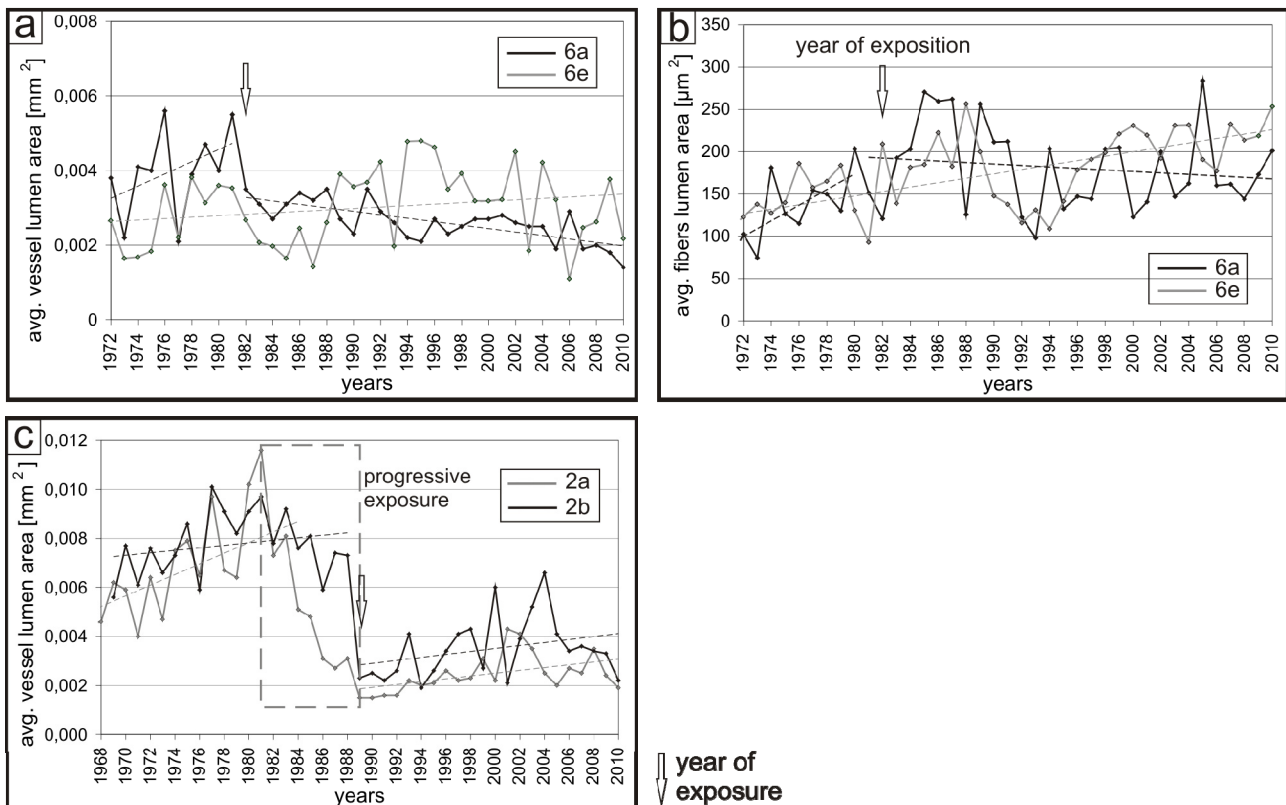lasts several years (up to 5 yrs). That gives the long-term erosion rates of ca. 0,6 mm/year (Fig. 7c).

Figure 7: Annual average cell lumen size changes within the roots taken from Rudzie Hill. Numbers of samples as in figure 4. a) vessels lumen size changes of exposed (6a) and burried (6e) part of the same root, b) fibres lumen size changes of exposed (6a) and burried (6e) part of the same root, c) progressive (2a) and sudden (2b) exposure of different parts of the same root.

The young, 1 meter deep, incision at gully head developed in late 80's which can be easily linked to the situation observed downstream among the basin. It was re-modelled after 10 years, at the beginning of XXI century. The gully was widened and slightly deepened but previously exposed roots became buried again. Between 1990 and 2000, there's no evidence of other erosive episodes.

Similar situation could be observed within the basins. There, the roots with scars were found underground and the field observations showed that several of nowadays exposed roots become partly covered by material transported along channel or from gully sides by mass movements. Presence of basins along middle part of gully extend the time that material eroded in head-retreating of the gully reaches the mouth and shorten the distance of transport during individual erosive episode. That results in flattening of longitudinal profile of the gully.

Summary

Dendrogeomorphological analysis proved diverse tendencies in development and transformation of gullies in different types of landscapes.

In the middle mountains extreme rainfall events contribute to deepening and widening of gullies. New gullies are developing mainly within old shallow valleys where water concentration during rainfall events is common. Extreme erosive processes are episodic but its geomorphological effects are long-lasting. In young-glacial landscape gully erosion is restricted mainly to the bottom of old gullies causing limited head-retraining and less significant transformation of gully sides.

Dendrogeomorphological analysis enables quantitative assessment of the role of extreme events in the transformation of mountains catchments. In young-glacial landscape such estimations are relevant only to individual segments of the gully due to great differences in erosion rates between erosive and transitional/accumulation segments. According to gullies in young glacial landscape dendrogeomorphological analysis allows dating the erosive episodes and reveals complicated pattern of erosion-accumulation processes along longitudinal profile of the gully.

Scattered events are typical in both study areas, but the scale and range of transformations of gullies is different. In middle mountains such an event concerns whole gully catchment and its effects are more or less recognisable for decades. Example from young glacial landscape exhibits far less effectiveness of gully erosion than in mountainous region. Erosive processes are restricted to upper parts of the gully and there scale of erosion is comparable to the mountainous conditions. However, further transformation of the gully (presence of basins, intermittent transport of eroded material on short distances) showed that the gully erosion in the lowlands in long-term scale is rather gradual process.

Acknowledgements

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